Water Resources Center Annual Technical Report FY 2011

Introduction

Delaware Water Resources Center

June 1, 2013

The Delaware Water Resources Center receives an annual Federal matching grant as authorized by section 104 of the Water Resources Research Act of 1984 (Public Law 98-242) as amended by Public Law 101-397, Public Law 104-147, and Public Law 106-374. The U.S. Geological Survey (USGS), Department of the Interior, administers the provisions of the Act. This annual evaluation report describes, in the format prescribed by the USGS, the research, training, and information transfer activities supported by the section 104 grants and required matching funds during fiscal year 2011.

Understanding the nature of the water quality and water supply problems faced in Delaware, historically and today, requires knowledge of the physiographic nature of the state, its climate, and major land uses. Geologically, Delaware is comprised of the Piedmont and Atlantic Coastal Plain Provinces. Only the northernmost 6% of the state is within the Piedmont, a region created of very old igneous and metamorphic rock. Soils range from well-drained, highly productive silt loams in the Piedmont to well– and excessively well-drained sandy loams and loamy sands in the Coastal Plain. Significant areas of poorly drained soils are also present, particularly in southeastern Delaware. Erosion and surface runoff are the main concerns in the Piedmont, while leaching of contaminants to shallow ground waters is the main water quality problem in the Coastal Plain. Average annual rainfall is plentiful (45 inches/year) and rather constant, averaging 3 to 4 inches/month in winter and spring and 4 to 5 inches/month in summer. Precipitation typically exceeds evapotranspiration by 12 to 18 inches/year, providing 10 to 12 inches/year of ground water infiltration.

Surface water is the main water supply source in the Piedmont, although the Cockeysville Formation is an important local aquifer of fractured marble and dolomite. This province is dominated by the Christina River Basin, fed by rivers that first flow extensively through Pennsylvania and Maryland. Water quality of the White Clay and Red Clay Creeks and Brandywine River is strongly affected by land use and point sources of pollution in neighboring states. Those rivers flow into the Christina River which, in turn, flows into the Delaware River.

Ground water is the major water supply source for the Atlantic Coastal Plain, a province of southeastwardly thickening unconsolidated and semi-consolidated sediments over crystalline basement rock. A primary aquifer in this province for water supply, stream base flow, and confined aquifer recharge is the unconfined Columbia aquifer. In a southwardly expanding wedge, the western portion of this area flows to the Chesapeake Bay through headwaters of the rivers and creeks of the Delmarva Peninsula's eastern shore. The mideast section of the province flows to the Delaware Estuary, fed by the watersheds of 15 creek and river systems. The southwest portion of the state flows into the Inland Bays of Delaware and Maryland and the Atlantic Ocean.

According to the Delaware Office of State Planning Coordination's 2007 Land Use/Land Cover data set, the major land use in Delaware is agriculture (526,070 acres; 41% of the 1.28 million acres in the state), which is dominated by a large, geographically concentrated poultry industry. Other main land uses are urban (19%), wetlands (19%), forests (15%), open water (4%), and barren land (1%). Delaware has 2509 miles of streams and rivers, 2954 acres of lakes/reservoirs/ponds, 841 square miles of estuarine waters, and 25 miles of ocean coastline. Approximately 2/3 of the state's wetlands are freshwater, and 1/3 is tidal.

Protection of the quality and quantity of the state's surface waters and aquifers is a major concern to all agencies and individuals responsible for water resource management in Delaware. Ground water protection is particularly important given the increasing reliance on this resource for drinking water. In general, the key priority water resource issues today are (not prioritized): (1) enhanced management and control of stormwater runoff, erosion and sediment; (2) improved understanding of sources, transport, fate, and remediation of toxic organics and trace elements; (3) comprehensive management of agricultural nutrients and sediment; (4) identifying sources of pathogenic organisms and preventing human health impacts; (5) increased understanding of the response of aquatic systems to pollutants; (6) identification and protection of wellheads and aquifer recharge areas; (7) better management of water supply and demand and development of a systematic means to deal with droughts and floods; (8) treatment and disposal of on-site sewage; (9) protection and restoration of wetlands; (10) prevention of saltwater intrusion to potable water supplies; and (11) protection of functioning riparian areas.

The Water Resource Problems of Delaware

Surface Water Quality

Point Sources: Delaware has a number of serious, documented surface water quality problems. Many can be traced back to point source pollution problems in past decades; others reflect ongoing anthropogenic activities that degrade surface water quality. Water quality is a major state environmental priority and improvements have occurred, particularly since the 1970s, due to the use of state and federal regulatory and funding means to address "end-of-pipe" point sources of surface water pollution. Much of this improvement was due to aggressive use of federal funding, available in the late 1970s and early 1980s under the Clean Water Act, combined with local funding, to expand and improve municipal wastewater treatment systems.

The National Pollution Discharge and Elimination System (NPDES) Program in Delaware has reduced the number of individual "point source" permits to discharge wastewater from over 200 in the 1970s to 50 as of 2011. Of those, nine are all or almost all stormwater, and six sites have no activity or greatly reduced activity. NPDES permitting programs have been expanded to address pollution in stormwater runoff from concentrated animal feeding operations (“CAFOs,” 350 permittees), construction (2238 permittees as of April 2009), and ongoing industrial activities (378 permittees). Current initiatives include implementation of “Total Maximum Daily Load”(TMDL) requirements, in a long term multi-state effort to reduce PCBs in the Delaware River, and implementation of “Best Technology Available” for cooling water intake structures which draw in tens and hundreds of millions of gallons per day of water from Delaware waters. Major reductions in oxygen demanding materials and toxics in surface waters have been achieved. Future investments in water quality will likely weigh the cost-effectiveness of further reducing point source pollution, versus non-point sources of water quality problems. Currently, the Federal American Recovery and Reinvestment Act and the State Clean Water Revolving Fund are providing funds for infrastructure to reduce point source pollution and other pollution sources.

The major surface water quality problems in Delaware include:

Urbanization: A rapidly expanding urban population is increasing pressures on Delaware’s surface waters. Rivers and streams are being affected by elevated temperature and low dissolved oxygen levels that can result from degradation of streambanks and stream channels. In residential and urban areas, increases in impervious surface have resulted in greater and flashier stormwater runoff, leading, in turn, to erosion, sedimentation, shallower water levels and destabilization of stream channels. Biological and habitat quality are also being affected by removal of stream buffers and stream bank "hardening" through use of riprap and concrete.

Drainage: Extensive drainage systems have been installed throughout the state, especially in coastal plain areas. Most were constructed in the 1930s and 1940s by the Civilian Conservation Corps and the Works Progress Administration. At that time, building a drainage ditch system involved channelizing and straightening headwaters of existing natural streams, then constructing ditches out and back from the channelized stream. Upland wetlands were often drained to reduce mosquito populations. A state "tax ditch program" is re-constructing ditches and in doing so wetlands are protected or augmented and management practices are used to minimize impacts to habitat. The effects on the biological and habitat quality of the waterway once it is stabilized are unknown. Another trend today is the proliferation of public ditch projects instead of tax ditches. Public funding makes the choice by landowners to tax themselves for reconstruction and maintenance of ditches less compelling. Public ditch projects are typically smaller (a few hundred feet) in scope and take place in the upper reaches of streams (typical bottom width is 3 feet) to augment mostly residential and some agricultural drainage. These projects are often carried out by the Conservation Districts. Nothing is known about the impacts to water quality or ecology from such projects. This lack of information may be important since protection of small headwater streams is critical to watershed health. Few streams in Delaware are unaffected by current or historic drainage projects that modify watershed drainage, natural stream channel configuration, buffers, and nutrient transport.

Nutrients: Nutrients are a leading cause of water quality degradation in Delaware. Nutrient effects can be seen especially in lakes, ponds, bays, and estuaries that receive nutrients conveyed by rivers, streams, and ground water. According to the State of Delaware’s April 1, 2010 combined 305(b) and 303(d) report, Delaware waters are generally considered to suffer from eutrophication and low dissolved oxygen related to nutrient enrichment. Primary land-based sources of nutrients in Delaware are agricultural practices, septic systems, and urban runoff. About 41% of Delaware’s land area is devoted to agricultural activities and 19% to urbanized uses. Delaware’s agricultural industry has a strong broiler industry component that heavily influences the state’s overall agricultural nutrient balance and has long created nutrient management problems because of the large amount of manure that must be land applied; commercial inorganic fertilizers used by farmers, other land managers and homeowners also contribute nutrients to ground and surface waters. About 70% of Delaware’s cash farm income comes from broilers, with annual production ranging from 260 to 280 million broilers, primarily in Sussex County, the largest broiler producing county in the U.S.

Other Problems: Toxics have affected Delaware waters resulting in fish consumption advisories for the Delaware River and Bay, Atlantic coastal waters including the Inland Bays, and twenty smaller waterbodies in 2009. The primary pollutant is polychlorinated biphenyl (PCB). Chlorinated pesticides, dioxins, and mercury have also been identified. Though PCBs have long been banned they are persistent in the environment and are transported from land to waters through runoff to settle in waterbody sediments where they enter the aquatic food chain. New designated uses and surface water quality standards as amended on July 11, 2004 indicate that pathogenic organisms in surface waters have negatively affected shellfish harvesting and caused 86% of Delaware’s rivers and streams to not fully support the swimming use; 98% do not fully support the fish and wildlife use. Most waters do not meet standards because of nonpoint source pollution impacts.

Ground Water Quality

The domestic needs of approximately two-thirds of the State’s population are met with ground water provided by both public and private wells. Most of the water used for agriculture, Delaware’s largest industry, and self-supplied industrial use, is also derived from ground water sources. A shallow water table and high permeability soils make Delaware’s ground water vulnerable to pollution. Shallow unconfined aquifers are especially vulnerable, though deeper confined aquifers are susceptible as well because they subcrop beneath and are recharged by unconfined aquifers.

Major ground water quality problems in Delaware today are:

Nutrients: Nitrates from agriculture and septic systems are, by far, the major contaminant in Delaware’s ground water. There are also some concerns about dissolved phosphorus transport to surface waters by shallow ground water flow in parts of the state where shallow water tables are interconnected with surface waters by ditches and/or tiles.

Organics: Hydrocarbons have also been found as have pesticides, though not at levels which cause alarm. A major source of hydrocarbons, such as MBTE, is leaking underground storage tanks (USTs) while agricultural activities are the source of pesticides. There are 12,050 regulated underground storage tanks in the State; 9651 have been properly abandoned and 2399 are still in use. Since the 1980s 314,040 releases to ground water have been confirmed and 2800 of those (USTs) have been closed. Over the period 2002-2003, 142 sites had confirmed releases with 30 confirmed ground water releases.

Salt Water Intrusion: Problems with private wells occur sporadically from seasonal salt water intrusion along the Delaware River and the Inland Bays/Atlantic Ocean coastal areas. No major problems have occurred and only one public well in Lewes required abandonment.

Trace Elements: Though not considered a health threat, iron concentrations are a widespread problem in Delaware for cosmetic reasons. Many public water supplies have treatment systems to remove iron. Thirty-four percent of 561 raw ground water samples analyzed by Delaware's Office of Drinking Water in 2002 exceeded the secondary contaminant level standard of 0.3 mg/L. Concerns exist about arsenic in ground waters because of the long-term application of this element in poultry manure to soils overlying shallow drinking water aquifers, the presence of brownfield soils in urban areas that had been used as tanneries or other industries, and the lowered drinking water standard for arsenic.

Wetlands Quality: Studies of nontidal wetlands in the St. Jones and Murderkill watersheds have recently been conducted. Beyond assessment of trends, primarily rate of loss, overall condition of wetlands and identification of major stressors affecting wetland function were recorded. These reports are found at: http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Pages/Wetland-Monitoring-and-Assessment.aspx.

Water Supply: Half of Delaware's population is located in the Piedmont (6% of land area) and uses surface water for drinking water. The other 50% of the population relies on ground water and is spread throughout the remaining 94% of the State. With regard to the amount of water used, ground and surface water are of equal importance; with regard to area served, ground water is overwhelmingly dominant. Capacity concerns are important north of the Christina River due to population concentration and the reliance on surface water. For the rest of the state, the reliance on abundant ground water and a diffuse pattern of development suggest that the supply of potable water is not currently a problem. Recent drought emergencies have brought water supply demand in northern Delaware into conflict with the need to maintain minimum pass-through flows in streams for protection of aquatic resources. Benthic organisms, the foundation of the aquatic food chain, cannot move to avoid dry stream bed conditions. This suggests that not maintaining pass-through flows at all times would be detrimental to stream aquatic life. Required pass-through flows can be high; the need to ensure those flows can result in practices or structures such as reservoirs that are economically inhibitory or may cause as much or greater environmental degradation as occasional dry stream bed periods.

Recent Initiatives Promoting Delaware Water Quality

Water quality standards for surface waters in Delaware, revised and adopted effective July 11, 2004 by the Delaware Department of Natural Resources and Environmental Control (DNREC), include amendments to protect swimmers by making bacteria standards consistent with U.S. Environmental Protection Agency guidance and 2000 federal Beaches Environmental Assessment and Coastal Health (BEACH) Act requirements.

To ensure that Delaware waters meet state, regional, and national water quality requirements and goals, the State has one of the most extensive water quality monitoring networks in the nation. Our water resources in this State are regularly tested for biological and chemical parameters. The results are reported in even years in the State's Watershed Assessment Report (305(b) report). Waters that do not meet water quality standards are listed in the State's 303(d) list. Both of these reports are available at:

http://www.dnrec.delaware.gov/swc/wa/Pages/WatershedAssessment305band303dReports.aspx. The extensive water quality data have allowed tracking of long term progress made towards improving Delaware's water resources.

Delaware's non-attainment of Clean Water Act standards as described in the 1996 303(d) list was addressed by a federal court order requiring the development of total maximum daily load (TMDL) regulations for nearly the entire state, according to a schedule that concluded in 2010 for nutrients and bacteria. TMDLs establish the maximum amount of pollutants a water body can receive daily without violating water quality standards, allowing the use of these waters for swimming, fishing, and drinking water supplies. TMDLs have been established for nutrients, bacteria, PCBs, and toxics. TMDL analysis documents and regulations can be found at: http://www.dnrec.delaware.gov/swc/wa/Pages/WatershedAssessmentTMDLs.aspx.

Additional programs are in place to ensure continued compliance with the court order and to achieve water quality standards. Now that TMDLs are in place, Pollution Control Strategies (PCSs) are being developed to address how, where and when pollutant loads will be reduced to achieve TMDL levels. The PCSs generally offer voluntary and regulatory strategies for urban, suburban and agricultural land uses and are developed through a public process where recommendations are made by Tributary Action Teams (TATs), groups of stakeholders formed with the purpose of addressing water quality concerns.

The first PCS in the State, developed to address the TMDLs in the Inland Bays watershed, has been finalized and can be found at: http://www.dnrec.state.de.us/water2000/Sections/Watershed/ws/ib_pcs.htm. PCSs for the Appoquinimink, Broadkill, Christina, Murderkill, Nanticoke, St. Jones, and Upper Chesapeake (Chester and Choptank) watersheds have been drafted and will each go through a public review process in the near future. In the Inland Bays, Nanticoke, Murderkill, and Appoquinimink watersheds, the Tributary Action Team (TAT) process and the development of a draft PCS has taken many years. An expedited process was developed to shorten the PCS development process, which was used in the Christina, St. Jones, Broadkill, Chester, and Choptank watersheds. A Team is currently being developed in the Mispillion and Cedar Creek watersheds and additional teams are expected to be formed in other impacted watersheds over the next several years. To follow progress of the TATs or get more information about them, go to: http://www.dnrec.state.de.us/water2000/Sections/Watershed/ws/.

Other DNREC Water Quality Initiatives Include:

Sediment and Stormwater Management Program: The current Delaware Sediment and Stormwater regulations require management of both stormwater quantity and quality of runoff. The first preference in management of runoff water quality is best management practices that promote recharge of stormwater such as Green Technology BMPs. These include filtering practices, and practices that allow for recharge such as filter strips, biofiltration swales, bioretention, and infiltration facilities. The regulations are currently undergoing revisions to address management of stormwater volume, provide for a watershed approach to stormwater management, and strengthen construction site stormwater management requirements. More information on the Delaware Sediment and Stormwater program is available at: http://www.swc.dnrec.delaware.gov/Pages/SedimentStormwater.aspx. More information specifically related to the proposed regulation revisions is found at: http://www.swc.dnrec.delaware.gov/Drainage/Pages/RegRevisions.aspx.

Non-point Source (NPS) Pollution: DNREC continues to reduce non-point source pollution through enhanced coordination of the Division of Watershed Stewardship's Cost Share Programs through the USEPA's NPS Management 319 Program and the National Oceanic and Atmospheric Association's (NOAA) Coastal NPS Management 6217 program along with the Delaware Nutrient Management Commission's (DNMC) program through the Delaware Department of Agriculture (DDA) and other programs. The effort allows DNREC to direct millions of dollars every year toward a comprehensive NPS program to reduce pollutant loads, restore streams and buffers, and install best management practices (BMPs) such as cover crops, nutrient management plans, manure storage structures, manure relocation, and urban best management practices within impaired watersheds. More information on the NPS 319 program is available at: http://www.dnrec.delaware.gov/swc/district/Pages/NPS.aspx, and information on Delaware's Coastal Management Program is available at: http://www.dnrec.delaware.gov/coastal/Pages/CoastalMgt.aspx.

Stream and Wetland Restoration: Rehabilitating stream corridors by reestablishing natural floodplains and sinuous low-flow channels, stabilizing stream banks, decreasing erosion, improving biological water quality, increasing wildlife habitat, providing buffers along the streams, establishing wetlands, promoting ground water recharge and water storage, controlling invasive plant species and reintroducing native species, trapping and uptake of nutrients are examples of the benefits that result from projects DNREC has implemented to improve the ecological quality and biological diversity in the State's watersheds. Several stream restoration projects completed in northern New Castle County within the past several years along Pike Creek include the Independence School (stream and wetlands), Meadowdale, Three Little Bakers Golf Course (stream and wetlands) as well as Delaware Park along Mill Creek. Wetland restoration projects that feature stormwater being filtered through a wetland before entering a stormwater basin were implemented at Christ the Teacher Catholic School, and the Hindu Temple.

Onsite Wastewater Treatment Systems (Septics): Delaware's "Regulations Governing the Design, Installation and Operation of On-Site Wastewater Treatment and Disposal Systems" were amended in 2002 and 2005 and are currently under review again by the Regulatory Advisory Committee. Legislation was also passed creating a Class H Licensed System Inspector Program which was part of the amended 2005 regulations. Other highlights of the amendments included advance treatment for systems greater than 20,000 gpd, use of effluent filters on all septic tanks, risers on all septic tanks, requirements for all licensees to take 10 hours of continuing education training annually, and for all subdivisions greater than 100 lots to use a community/cluster system with advance treatment. Grant funds have been used in the past few years to implement a septic system pumpout and inspection program, and a holding tank inspection and pumpout program in Sussex County. Both programs have been very successful in identifying failing systems and allowing DNREC to provide assistance to system owners in making repairs or replacements as needed. Resources for the septic inspection and pumpout program only lasted two years as it was a pilot program. However, the holding tank inspection and pumpout program is still operating and has moved statewide with an annual 98% compliance rate. DNREC has also worked with the wastewater community to develop performance standards for nitrogen and phosphorus of onsite wastewater systems which should be incorporated in the revisions to the statewide regulations in the near future. In 2008 the "Regulations Governing the Pollution Control Strategy for the Indian River, Indian River Bay, Rehoboth Bay, and Little Assawoman Bay Watershed" were adopted and in these regulations the performance standards for nitrogen and phosphorus of on-site wastewater systems were adopted as well as the requirement for inspection of septic systems prior to the sale of properties that utilizes septic systems. To view these regulations, go to: http://www.wr.dnrec.delaware.gov/Services/Pages/GroundWaterDischarges.aspx.

Source Water Assessment and Protection: The DNREC Source Water Assessment and Protection Program (SWAPP) provides for the assessment and protection of sources of public drinking water, both surface and ground water. The assessment consists of three critical steps: first, delineation of source water areas; second, identification of existing and potential sources of contamination; and finally, assessment of the susceptibility of the source water area to contamination. The Site Index Database identifies the location and status of both existing and potential sources of contamination within the State. Most potential point sources have been mapped and rated. In 2004, the Source Water Protection Program developed a guidance manual for local governments. This document was updated in 2005. For more information on source water protection, go to: http://www.wr.udel.edu/swaphome/index.html. Delaware SWAPP is a cooperative effort between DNREC, Delaware Division of Public Health, and the University of Delaware's Water Resources Agency. A citizen's advisory group (CTAC) was formed to assist DNREC in the development and implementation of the program and to ensure public involvement. SWAPP is a multi-phase program that is expected to be completed in the next few years.

Cooperative Efforts: Cooperation among DNREC, residents, other agencies-state and federal, universities, county and municipal governments, conservation districts, and non-governmental organizations (NGOs) helps bring Delaware water goals to fruition. Pollution Control Strategy development and implementation of TMDL regulations is driven by Tributary Action Teams (TATs). The Center for the Inland Bays, University of Delaware Cooperative Extension, the Sea Grant Program at the University of Delaware College of Earth, Ocean, and Environment, University of Delaware Water Resources Agency, Delaware State Cooperative Extension, the Camden-Wyoming Rotary Club, the State of Delaware's Nutrient Management Commission, New Castle, Kent and Sussex County governments, Sierra Club, the county conservation districts, USDA, other DNREC divisions and many others have been vital contributors in the development of PCSs and TATs.

All of the projects implemented in TMDL watersheds to address water quality concerns require a cooperative effort and partnerships to be formed, not just in government interactions, but between members of TATs as well. Finding a solution for cleaner water will require more innovative solutions, greater regulatory control, additional financial resources, and a willingness to make a change by everyone affecting Delaware's watersheds, as we are all part of the problem and we must work together to find a reasonable solution for everyone.

Delaware Water Resources Center: An Overview

The Delaware Water Resources Center (DWRC) has been a part of the University of Delaware since 1965. From 1965 until 1993 the DWRC was located in the University of Delaware's Research Office. In 1993, the DWRC was formally moved to the College of Agriculture and Natural Resources (CANR) where, since 1997, Dr. Tom Sims, Deputy Dean for Academic Programs and Research, has served as DWRC Director. The DWRC works with all organizations and agencies in Delaware with an interest or responsibility in water resources. We have a 12- to 15-member Advisory Panel representing a wide variety of water resource backgrounds. We regularly cooperate with the Delaware Water Resources Agency, Delaware Geological Survey, Delaware Department of Natural Resources and Environmental Control, the Center for the Inland Bays, the Delaware Nutrient Management Commission, Delaware State University, USDA Natural Resources Conservation Service, Delaware Nature Society, and The Nature Conservancy, to name but a few. The DWRC has always supported a wide range of water resource related research, education, and information transfer programs. We cooperate with many academic departments and units that conduct water-related research at Delaware State University's Department of Agriculture and Natural Resources and the University of Delaware (UD), including the UD Water Resources Agency in the Institute for Public Administration, the Institute for Soil and Environmental Quality at UD, the UD Departments of Biological Sciences, Bioresources Engineering, Chemistry, Civil and Environmental Engineering, Geography, Geological Sciences, and Plant and Soil Sciences, as well as the UD Colleges of Agriculture and Natural Resources; Arts and Sciences; Engineering; and Earth, Ocean, and Environment. Close communication is maintained between the DWRC and state natural resource agency representatives and water officials to address priority water quality and water quantity concerns in the state. Through efforts such as these, the DWRC has provided key stakeholders a forum for discussion and an opportunity for education regarding water resources.

Section 104 Objectives

The DWRC has defined a three-fold mission to meet the goals of the Water Resources Research Act:

(1) To support research that will provide solutions to Delaware's priority water problems;

(2) To promote the training and education of future water scientists, engineers, and policymakers; and

(3) To disseminate research results to water managers and the public.

To meet these goals we have focused our efforts into three major areas:

(1) Graduate Fellowship Program: A competitive graduate fellowship program supports graduate fellows on a three-year cycle. Of the two Ph.D. graduate fellows supported during the period of this report, one is in the UD College of Agriculture and Natural Resources and the other is in the UD College of Arts and Sciences. Their research focuses on quantifying carbon amount and quality for transport of contaminants in landscapes and microbiome of the eastern oyster.

(2) Undergraduate Internship Program: We initiated a highly successful undergraduate internship program in 2000. In the first twelve years, over 100 undergraduate internships were made possible via funding from DWRC/USGS, four Colleges within the University of Delaware (UD), UD's Institute of Soil and Environmental Quality, Delaware Geological Survey, DNREC, and the Department of Agriculture and Natural Resources at Delaware State University. DWRC interns work with faculty to conduct research, prepare a written project report, and present their findings at an annual poster conference.

(3) Information Transfer: The DWRC website and newsletters are sources of up-to-date information on DWRC activities and water-related issues of importance to Delaware and the region. Our website provides information on water resources problems, links to water-related organizations, internship and job opportunities in water resources, a calendar of upcoming events, and a Kids Zone for teachers and parents. We also co-sponsor state-wide conferences on water resource topics of current interest.

Delaware Water Resources Center Program Goals and Priorities

1. Institute Director: Dr. J. Thomas Sims, T.A. Baker Professor of Soil and Environmental Chemistry, Deputy Dean, College of Agriculture and Natural Resources, Director, Delaware Water Resources Center, and Institute of Soil and Environmental Quality, 113 Townsend Hall, University of Delaware Newark, DE 19716-2103, Phone: 302-831-2698, FAX: 302-831-6758, email: jtsims@udel.edu

2. Administrative Personnel: Maria Pautler, Program Coordinator, Phone: 302-831-0847, FAX: 302-831-0605, email: mpautler@udel.edu

3. Abstract of Program and Management Overview: The Delaware Water Resources Center (DWRC) research, education and information transfer programs focus on issues of state and regional importance to both water quality and water quantity. Long-term priority areas of the DWRC have included nonpoint source pollution of ground and surface waters, development of ground water supplies, the impact of hydrologic extremes on water supply, and socio-economic factors affecting water supply and water quality. In 2000, the DWRC Advisory Panel identified five specific areas for near-term DWRC research efforts: (1) Agricultural nutrient management and water quality; (2) Basic and applied research on sources, fate, and transport of water pollutants; (3) Quantifying response of aquatic ecosystems to pollutant inputs; (4) Water supply, demand, and conservation, as affected by changing land uses in Delaware and the mid-Atlantic states; and (5) Management and control of stormwater runoff. The FY11 DWRC public water conservation/educational outreach program addressed these issues. DWRC’s research program during the same period addressed these concerns by supporting graduate fellowships in water quality, an undergraduate student internship program, and public information forums including an intern research poster session and a statewide water resources conference.

2011-2012 DWRC Fellowship and Internship Research Program

Two fellowships were funded for the first year in 2011-2012 based on satisfactory progress reporting to the DWRC Advisory Panel:

a) Quantifying the Role of Carbon Amount and Quality for Transport of Contaminants on Our Landscapes: A Watershed Scale Model

Graduate Fellow: Gurbir Dhillon; Advisor: Shreeram Inamdar, Department of Bioresources Engineering, College of Agriculture and Natural Resources, University of Delaware.

b) Microbiome of the Eastern Oyster, *Crassotrea virginica*

Graduate Fellow: Eric Sakowski; Advisor: Eric Wommack, Department of Plant and Soil Sciences, College of Agriculture and Natural Resources, University of Delaware.

Eight internships were awarded for 2011-2012 based on a review of proposals submitted by potential undergraduate interns and their advisors to the DWRC Advisory Panel:

a) Spatio-Temporal Hydrodynamic Variability in a Small Tidal Creek: DNERR St. Jones Reserve

Undergraduate Intern: Rebecca Aiken; Advisors: Jack Puleo, Department of Civil and Environmental Engineering, College of Engineering, University of Delaware and Tom McKenna, Delaware Geological Survey.

b) Oyster Gardening in Delaware Inland Bays: Filtration as a Means to Remove Excess Nitrogen from Local Wastewater Treatment Plant Discharges

Undergraduate Intern: Amy Cannon; Advisor: Gulnihal Ozbay, Department of Agriculture and Natural Resources, Delaware State University.

c) Characterization of Submarine Groundwater Discharge Sites in a Coastal Lagoon

Undergraduate Intern: Stephen Gonski; Advisor: A. Scott Andres, Delaware Geological Survey.

d) White Clay Creek Wild and Scenic Shad Restoration Project

Undergraduate Intern: Chelsea Halley; Advisor: Gerald Kauffman, UD Water Resources Agency.

e) Predation of Bacteria by the White Rot Fungi, *Pleurotus ostreatus*

Undergraduate Intern: John Paul Harris; Advisor: Anastasia Chirnside, Department of Bioresources Engineering, College of Agriculture and Natural Resources, University of Delaware.

f) Is Atmospheric Deposition and Washoff of Aluminum in Stemflow a Significant Source of Aluminum to Forest Soils?

Undergraduate Intern: Carrie Scheick; Advisor: Delphis Levia, Department of Geography, College of Arts and Sciences, University of Delaware.

g) Hydraulic Properties of the Columbia Aquifer

Undergraduate Intern: Nicholas Spalt; Advisor: A. Scott Andres, Delaware Geological Survey.

h) Sediment Transport through Historic Mill Dams of the Christina River Basin

Undergraduate Intern: Kimberly Teoli; Advisor: James Pizzuto, Department of Geological Sciences, College of Earth, Ocean, and Environment, University of Delaware.

Research Program Introduction

None.

Microbiome of the Eastern Oyster, Crassastrea virginica

Basic Information

Title:	Microbiome of the Eastern Oyster, Crassastrea virginica
Project Number:	2010DE171B
Start Date:	3/1/2011
End Date:	2/28/2012
Funding Source:	104B
Congressional District:	At large
Research Category:	Ecological Processes
Focus Category:	Ecology, Non Point Pollution, Conservation
Descriptors:	None
Principal Investigators:	Eric Wommack

Publications

1. Sakowski, E. and E. Wommack, 2011, Exploring the Commercial Microbial Communities of the Eastern Oyster, <i>Crassostrea virginica<i> Progress Report, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 16 pages.
2. Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2 DWRC Spotlight on Graduate Research, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 7.
3. Sakowski, E. and E. Wommack, 2012, Exploring the Commensal Microbial Communities of the Eastern Oyster, Crassostrea virginica. Progress Report, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 16 pages.

Project Title: Exploring the commensal microbial communities of the Eastern Oyster, *Crassostrea virginica*

Investigators: Eric Sakowski, Dr. K. Eric Wommack

<u>Background/ Justification</u>

The American Eastern oyster, *Crassostrea virginica*, plays a vital ecological and economic role throughout its home range. Naturally occurring from the Gulf of St. Lawrence in Canada to the coast of Brazil (Comeau, Pernet et al. 2008), *C. virginica* forms oyster reefs that act as erosional breaks within estuaries and provide protection from predators for many invertebrates and small fish. In addition, *C. virginica* reduces turbidity and improves water quality as it filters water to feed. These oysters are capable of filtering water at a high rate – up to 6.8L h^{-1} (Riisgard 1988) – for a few hours at a time. It is estimated that in colonial times, oysters filtered the entire volume of the Chesapeake Bay (68 trillion liters) in as little as three days. Today, the process takes over a year as the population of oysters in the region has dropped to one percent of historical values.

The decimation of *C. virginica* populations began in the late 19th century as a result of over-harvesting and habitat degradation (Rotschild, Ault et al. 1994). Since the 1950s, two protozoan diseases introduced to the area, *Haplosporidium nelsoni* (the causative agent of the disease MSX) and *Perkinsus marinus* (which causes Dermo), have resulted in oyster mortality and further population decline (Ewart and Ford 1993). Despite these difficulties, the oyster industry remains an important fishery, with an estimated value of over $100 million annually (NOAA NMFS, 2004).

Thus, the study of oyster health and susceptibility to disease is of ecological and economic concern. Understandably, the majority of research regarding oyster microbiology has focused on MSX and Dermo (reviewed in Lafferty, Porter et al. 2004), as well as human pathogens associated with raw shellfish consumption. One area of interest that remains largely unexplored, however, is the impact of commensal microbial communities on oyster ecology and health. Studies of microbial-metazoan relationships in other organisms have demonstrated that commensal microbial communities can influence efficiency of energy extraction from food and may help regulate body weight (Turnbaugh, Ley et al. 2006). Commensal microbial diversity has also been inversely correlated with pathogen colonization in both chickens (Nisbet 2002) and humans (Klepac-Ceraj, Lemon et al. 2010).

Studies of sessile marine invertebrates have shown commensal microbial composition to be host specific, differ from surrounding water and play a role in regulating various metabolic and biogeochemical processes (Raina, Tapiolas et al. 2009; Pfister, Meyer et al. 2010). However, many oyster-related microbial studies have examined the presence/absence of pathogenic bacteria (Lee, Panicker et al. 2003) or phages infecting those bacteria (DePaola, Motes et al. 1998), while knowledge of microbial community structure, dynamics, and impacts on oyster health remain limited. One of the major hurdles to such investigations has been the inability to cultivate >99% of environmental bacteria and viruses (Kennedy, Flemer et al. 2010). The decreasing cost of high-throughput sequencing has now made it feasible to examine microbial communities at a high resolution across many samples. This project seeks to utilize next-generation sequencing technology to examine oyster-associated commensal microbial community structure and dynamics over time and between healthy and diseased individuals.

<u>Objectives</u>

This project seeks to:

1.) Determine the abundance of bacteria and viruses in oyster extrapallial fluid and water over time
2.) Identify commensal bacterial diversity within extrapallial fluid and surrounding water using molecular-based approaches
3.) Identify viral diversity within extrapallial fluid and surrounding water using molecular-based approaches
4.) Examine the influence of local geography on variation in microbial communities
5.) Observe differences in the commensal microbial communities of healthy and MSX or Dermo-infected oysters

<u>Methodology</u>

Annual survey sample collection. Five oysters were harvested each month beginning in October 2010 from the Smithsonian Environmental Research Center (SERC) in Edgewater, MD and transported 20 minutes to Annapolis, MD for processing. Each oyster was rinsed with DI and scrubbed with 70 percent ethanol prior to mantle fluid extraction. A hole was drilled into the posterior end of the oyster at the interface between valves. Mantle fluid was extracted using a 5mL syringe. Samples were placed on ice and transported back to Newark, DE for further processing. A 10L water sample was collected at the same site and time as the oysters. The sample was placed in a cooler filled with water from the site to maintain temperature for transport back to Newark, DE.

Local geography variation collection. Ten oysters and two 10L water samples were collected at four oyster bars located within 3 miles of one another on the Choptank River, a tributary of the Chesapeake Bay (Figure 7). Oyster samples were obtained by dredging. Water samples were obtained by deploying a niskin bottle ~1m above the reef. Oysters were kept on ice prior to processing. Water samples were processed on site.

Disease survey. Ten oysters and a 10L water sample were collected from 4 Maryland Department of Natural Resources disease-monitoring stations in the Chesapeake Bay (Figure 8). Two of the chosen sites have historically high levels of Dermo infection, while two have low levels. Oyster and water samples were processed on site. Oyster tissues were tested for the presence of MSX and Dermo by histologist Carol McCollough of MD DNR.

Bacterial and viral counts. A 200μL aliquot of each oyster sample was combined with 37% formalin to a final concentration of 1%, snap-frozen in liquid nitrogen, and stored at -80°C to be used for bacterial and viral counts. Likewise, 4.5mL of the sample water was combined with 37% formalin and frozen for counts. Samples were thawed on ice and combined with 0.22μm-filtered 1x PBS in the following ratios: 10µL extrapallial fluid in 990µL PBS for oyster samples; 70µL water in 930µL PBS for water samples. The solutions were rocked at 30°C for twenty minutes and then vacuum filtered onto a Whatman 0.02µm, 13mm Anodisc filter. Filters were stained with 400µL of 2.5x SYBR Gold in the dark for fifteen minutes prior to being mounted onto slides. Slides were placed at -20°C until viewing.

Bacteria and viruses were visualized using epifluorescence microscopy with a 40X oil-immersion objective. Pictures were taken at 15 randomly-selected sites on each filter. Viruses were counted using the iVision software. Bacteria were counted manually. Bacterial and viral abundances were calculated based on the following equation: $Vt = Vc \div Fc \times At \div Af \div S$, where Vt = viral abundance mL^{-1}, Vc = total number of viruses counted, Fc = total number of fields counted, At = surface area of the filter (μm^2), Af = area of each field (μm^2), and S = volume of sample filtered (mL) (Suttle and Fuhrman 2010).

Bacterial DNA isolation. Oyster samples were combined with 1x PBS buffer at a 1:25 ratio and rocked for 1 hour at 30°C. Samples were then filtered through a Millipore Sterivex 0.22µm filter unit. Approximately 500mL of water was pumped through a Millipore Sterivex 0.22µm filter.

DNA was extracted from each of the filters as follows: 10µL of proteinase-K (20mg/mL) and 20µL of lysozyme (100mg/mL) were combined with 1mL of DNA Extraction Buffer (DEB; 100 mM Tris buffer (pH 8), 100 mM NaEDTA (pH 8), 100mM phosphate buffer (pH 8), 1.5 M NaCl, 1% CTAB) and added to the filter. Filters were incubated at 37°C for 30 minutes and the samples transferred to 2.0mL microcentrifuge tubes. Samples were frozen at -80°C for 15 minutes and thawed at 37°C for 5 minutes three times, followed by incubation in a 37°C water bath for 30 minutes. 100µL of 10% SDS was then added and the sample incubated for 2 hours in a 65°C water bath. The microcentrifuge tubes were then filled to the top with phenol:chloroform:isoamyl alcohol(25:24:1) and centrifuged at 3000rpm for 5 minutes at 4°C. The top layer was transferred to a new microcentrifuge tube and the phenol:chloroform:isoamyl alcohol step repeated. The top layer was transferred to a new tube and combined with 0.6 volumes of room temperature 100% isopropanol. Samples were incubated at room temperature overnight and then centrifuged at 13,000rpm for 30 minutes. The isopropanol and buffer were removed and 1mL of 70% ethanol added. Samples were centrifuged at 13,000rpm for 10 minutes. The ethanol was removed, followed by a second addition of ethanol and centrifugation. The pellet was then allowed to dry and resuspended in 1x TE buffer. Pellets were allowed to dissolve for one hour at 4°C and then stored at -80°C.

16S amplification, barcoding, and sequencing. Forward primer 27F and reverse primer 334R with a unique barcode were used to amplify ~300bp sections of the 16S rRNA gene from 3 oyster and 2 water samples each month. Primers were obtained from the Institute for Genome Sciences. PCR amplification of samples was performed using the following conditions: 95°C for 5 minutes; 33 cycles of 95°C for 30 seconds, 52°C for 30 seconds, 72°C for one minute; 72°C for 7 minutes. PCR reactions were run on a 1.8% agarose gel. Bands were excised using the Qiaquick Gel Extraction kit. Samples were sent to IGS and sequenced using the Roche 454

Genome Sequencer FLX Titanium system. Operational taxonomic unit (OTU) analysis was performed using the Quantitative Insights into Microbial Ecology (QIIME) software (Caporaso et al. 2010).

Results and Discussion

Bacterial and viral abundance. Bacterial and viral abundance were measured from 5 oysters and one 10L water sample once per month. Sample collection began in October 2010 at the Smithsonian Environmental Research Center (SERC) and is still ongoing. At the time of this writing, bacterial and viral abundance has been tracked for 12 months. However, at this time sequence data has only been analyzed for the first five months of the year-long study; therefore, only abundances corresponding with the sequenced samples are being presented here. Bacterial and viral abundances were variable from month to month. In general, viral (Figure 1A) and bacterial (Figure 1B) abundances were greater in the extrapallial fluid of oysters than the surrounding water, while viral:bacterial ratios were significantly greater in oysters than water ($p < 0.05$). Both bacterial and viral abundances were significantly greater ($p < 0.05$) in oyster extrapallial fluid for three of the five months sampled. This may be due to the environment within the oyster extrapallial fluid being more conducive to bacterial growth.

Bacterial diversity and community composition. Bacterial diversity was similar for oyster and water samples collected from October 2010 to March 2011, as determined by both the Shannon (Figure 2A) and Chao1 (Figure 2B) indices. Despite similar diversity measures, the two environments differed in community composition. Unweighted UPGMA hierarchical clustering was performed with 10 jackknife replicates on oyster and water libraries. This approach considers only the presence/absence of bacterial operation taxonomic units (OTUs) and ignores relative abundance. A tree of the hierarchical clusters shows a distinct split between oyster and water bacterial samples (Figure 3). This was supported by Principle Coordinate Analysis (PCoA) of the samples, which showed tight clustering of oyster samples and a distribution of water samples along the y-axis (Figure 4A). Coloring the samples by month indicates a clear progression of water samples over time, a pattern that was not readily discernable in the oysters (Figure 5).

Weighted PCoA analysis of oyster and water samples, which accounts for both presence/absence and relative abundance of OTUs, displays a distinctly different pattern (Figure 4B). In the weighted approach, water samples cluster more closely together and the oyster samples are more widely dispersed. Considered together with the unweighted analysis, this result suggests oyster samples are comprised of a stable community of bacterial species that vary in relative abundance from month-to-month (hence tight clustering in the unweighted approach and widespread distribution in the weighted), and water samples have a few dominant members but vary in the composition of rarer members. A survey of the bacterial genera present in each environment supports this. 23% of all bacterial genera identified in oyster sequences were present in all 5 months, and these persistent genera made up an average 86% of the community. In contrast, only 8% of the genera observed in water samples were present in all 5 months. These persistent water genera comprised on average 68% off the community. Therefore, on a per genera basis, the persistent bacteria in water samples were more abundant than their oyster counterparts, but water samples still contained a greater proportion of transient genera.

The distinct differences in communities suggest certain bacteria may be selected for one environment or the other. To determine whether OTUs were associated with only one environment, a G-Test of Independence was performed (Table 1). 15 sampled OTUs were identified as being significantly associated with only one environment, 11 of which were unique to oyster samples. On a broader taxonomic evaluation, however, only the Deltaproteobacteria were found to be significantly enriched in oyster samples (Figure 6). It remains unclear the impact of these bacteria on the oyster (see Future Work).

Future Work

16S libraries for the remaining 7 months of the annual study have been sequenced (data obtained earlier this week). The libraries will be analyzed in a manner similar to the sequences above to look at bacterial community composition and dynamics over the year. DNA has been isolated from the Choptank River samples obtained in June 2011 and are being prepared for sequencing at the present time. Samples obtained from the disease monitoring stations are awaiting DNA isolation. Each sample from the disease monitoring stations will be paired with the health status of the sampled oyster. Libraries of both healthy and infected oysters will be compared within and between sample sites to look for changes in bacterial communities that correlate with disease. Monthly samples are still being collected from SERC to potentially examine a 2-year period of time.

The increased abundance of Deltaproteobacteria in oyster samples is interesting, particularly since these organisms produce hydrogen sulfide during metabolism, which is toxic to most organisms. In order to determine whether these organisms are metabolically active, I am planning on examining mRNA levels of Dissimilatory Sulfide Reductase, an enzyme in the sulfate reduction pathway conserved among sulfate-reducing bacteria, in oyster samples using qRT-PCR.

Viral particle isolation and library construction is still under methods development.

Conclusions and Project Implications

This study is a longitudinal examination of the relationship between microbial communities within the extrapallial fluid of *Crassostrea virginica* and surrounding water. Bacterial and viral abundances were greater in oyster samples than the surrounding water. While oyster and water bacterial communities were similarly diverse, they differed both compositionally - several OTUs were identified exclusively in oyster samples – and dynamically. Oysters bacterial communities appear to maintain a stable core community, while water bacterial communities showed a greater fluctuation of genera that changed from month to month. Additionally, oyster samples displayed a significantly greater proportion of Deltaproteobacteria. The unique composition and dynamics of the oyster-associated bacterial community suggests that the oyster microbiome may play a key role in oyster fitness or resistance/ susceptibility to disease. Future work will explore the potential impacts of this unique commensal community and provide a greater understanding of how to better protect this keystone species.

Abstract

The Eastern Oyster, *Crassostrea virginica*, is an important economic and ecological resource along the east coast of North America. Since the 1950s, populations within the Chesapeake and Delaware Bays have been subject to outbreaks of MSX and Dermo, two diseases caused by parasitic protozoans. Interest in oyster microbiology has primarily focused on the causative agents of these two diseases, *Haplosporidium nelsoni* and *Perkinsus marinus*, respectively, as well as human pathogens associated with consumption of raw shellfish. Little is known about the commensal microbiome associated with oysters despite an increasing appreciation of the impacts of these communities on the biology and health of their metazoan hosts. In this study, the microbial communities within oyster extrapallial fluid and the surrounding water were compared monthly from October 2010 to February 2011. Bacterial and viral abundances were significantly greater in extrapallial fluid than water for three of the five months ($p < 0.05$). 16S rRNA gene amplification and high-throughput sequencing were leveraged to investigate bacterial community composition. Bacterial diversity was similar between environments when measured with both Shannon and Chao1 indices. However, bacterial community composition was different between extrapallial fluid and water samples. Several OTUs were associated exclusively with oyster samples. Furthermore, Deltaproteobacteria were significantly enriched ($p < 0.05$) in oyster samples as compared to water. A better understanding of the unique microbial community commensal with the eastern oyster may provide new direction for improving the fitness of this species.

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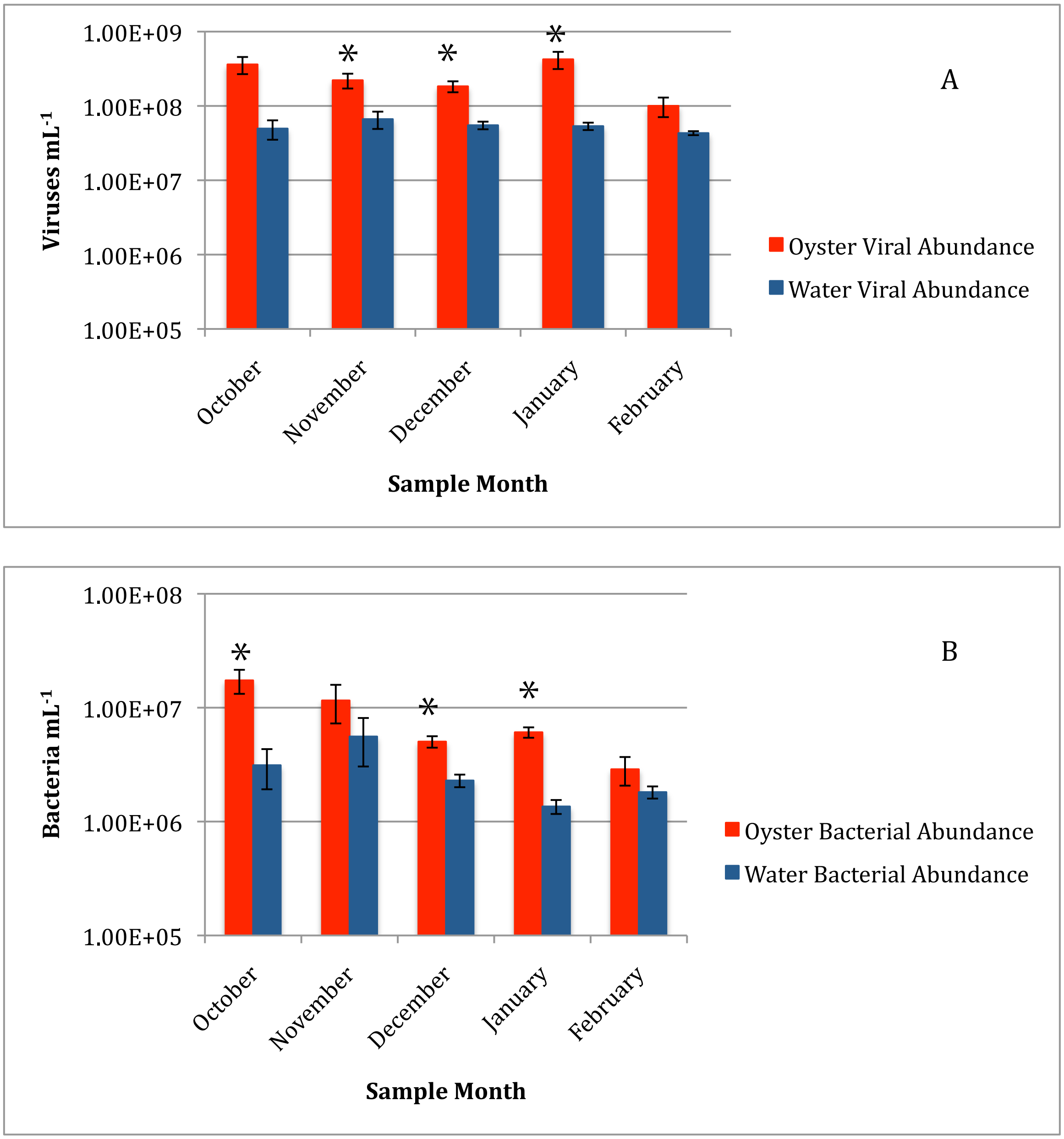

Figure 1. Viral and bacterial abundances within the extrapallial fluid of *Crassostrea virginica* and surrounding water from the Rhode River in Edgewater, MD. Abundance was determined by epifluorescence microscopy. Standard error was calculated for four oysters and replicate water samples each month. * = $p < 0.05$.
A.) Viral abundances of oyster and water samples collected from October 2010 to February 2011.
B.) Bacterial abundances of oyster and water samples collected from October 2010 to February 2011.

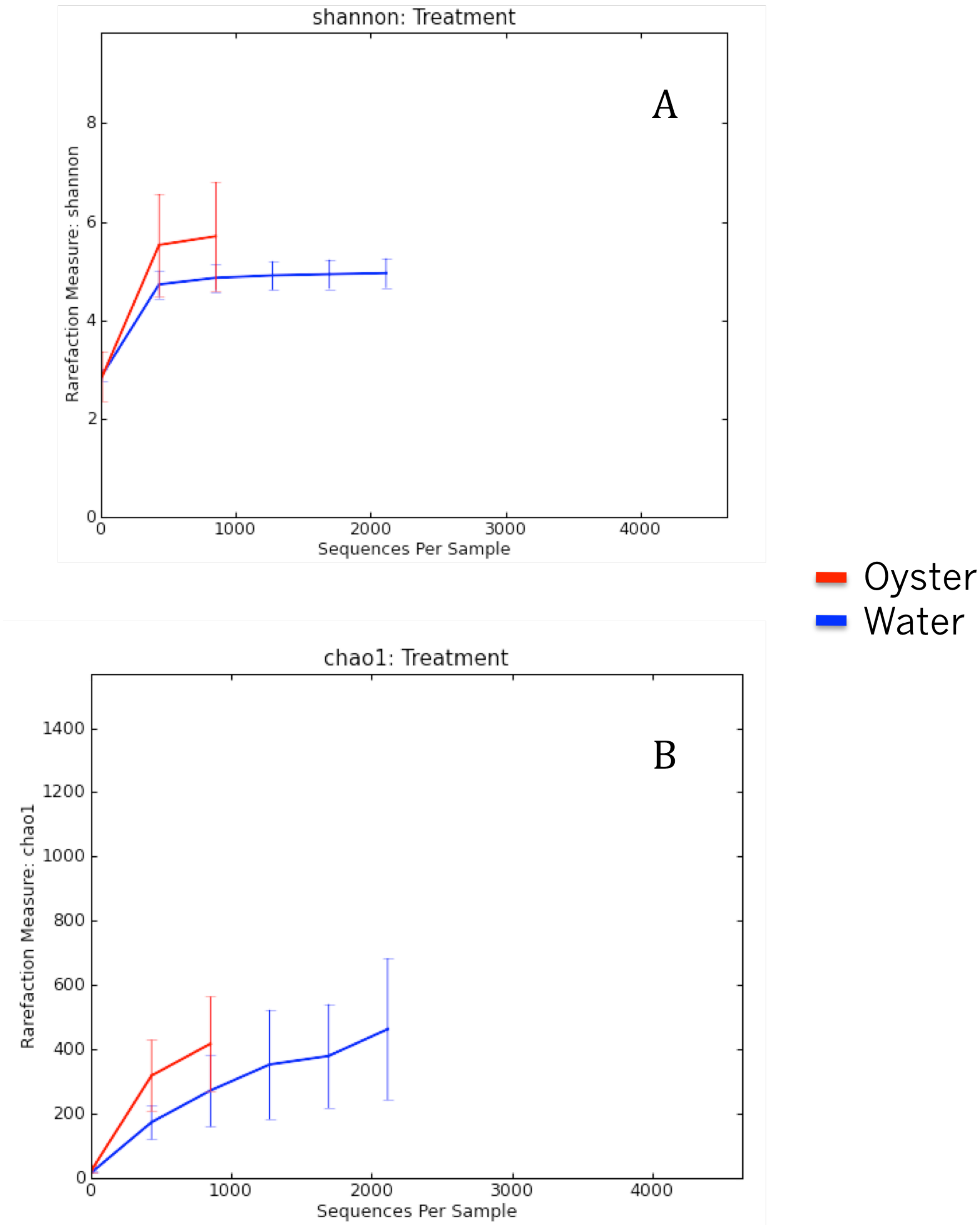

Figure 2. Measures of diversity for oyster and water samples using both the Shannon Index (A) and the Chao1 Index (B). Diversity was not significantly different for oyster and water samples using either index. Samples were measured at 852 sequences per sample based on the greatest number of sequences for the smallest library.

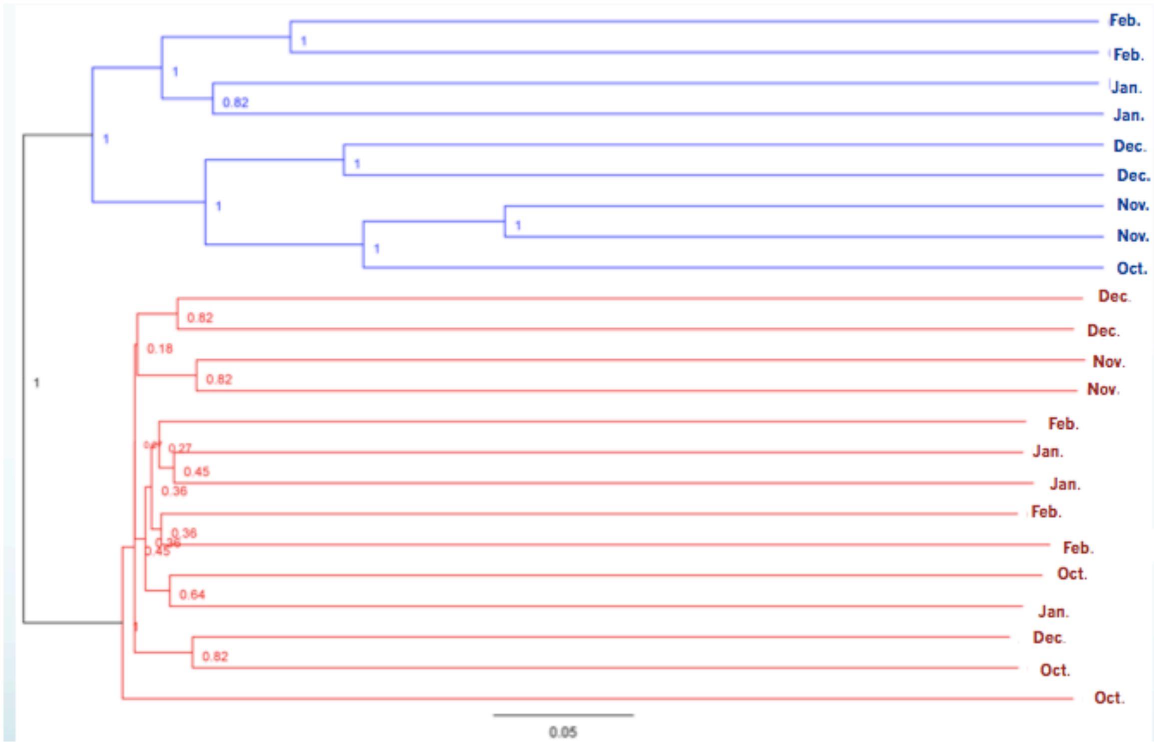

Figure 3. UPGMA hierarchical clustering of oyster (red) and water (blue) samples. 16S rRNA gene sequence libraries for 3 oyster and 2 water samples collected from October 2010 to February 2011 were sequenced and analyzed. Libraries were resampled 10 times to determine jackknifing support, which are indicated by node values.

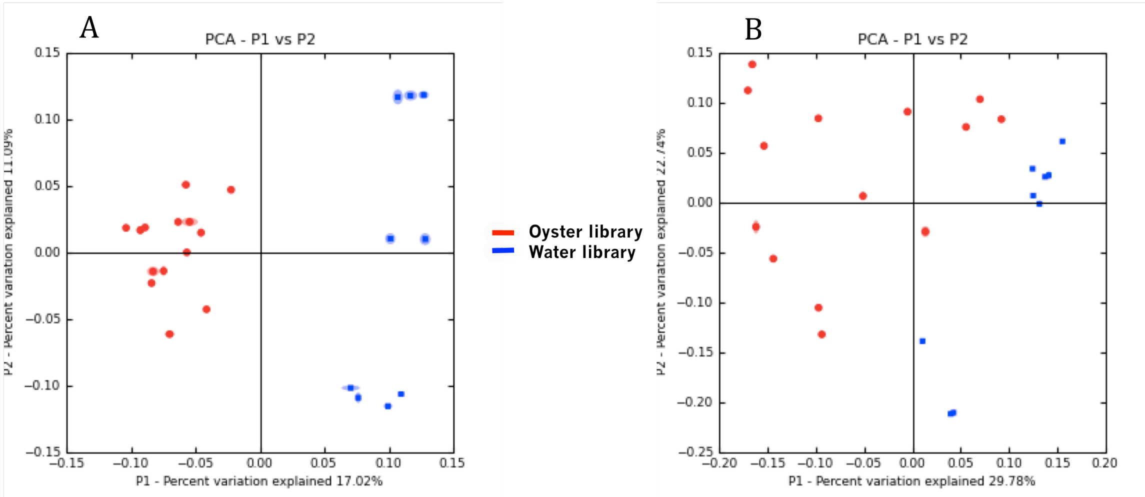

Figure 4. Principle coordinate analysis of A.) unweighted and B.) weighted oyster (red) and water (blue) 16S libraries. Ellipses surrounding points are confidence ellipsoids from 10 jackknifing replicates.

Figure 5. Three-dimensional Principle Coordinate Analysis of unweighted oyster and water 16S libraries colored by sample month. Water samples are circled. Ellipses are confidence ellipsoids from 10 jackknifing replicates.

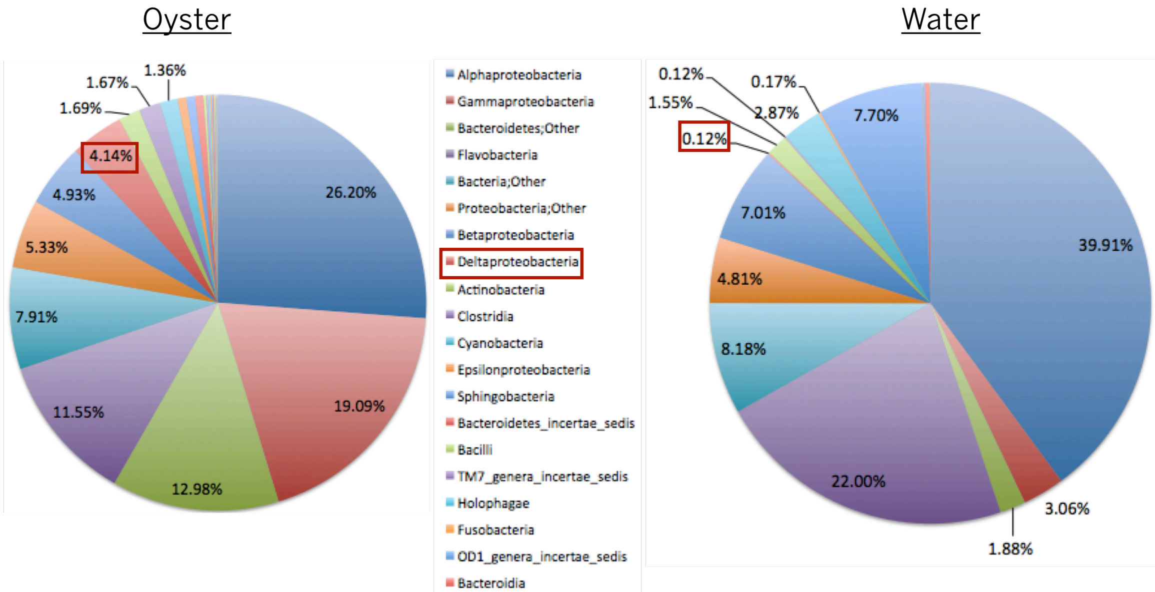

Figure 6. Average taxonomic distribution of oyster and water samples from October 2010 to February 2011. During the months analyzed, only Deltaproteobacteria were significantly different in abundance between the two environments ($p < 0.05$; red boxes).

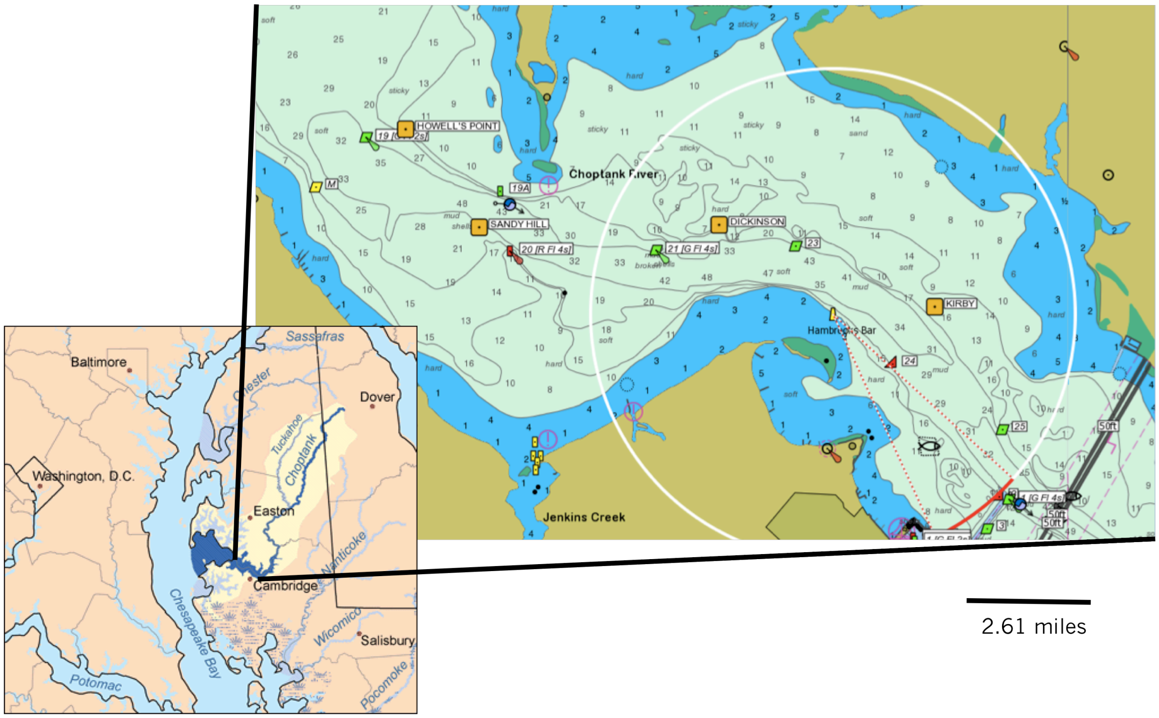

Figure 7. A map of the oyster bars sampled from the Choptank River in June 2011. Sampled bars are depicted by the yellow squares.

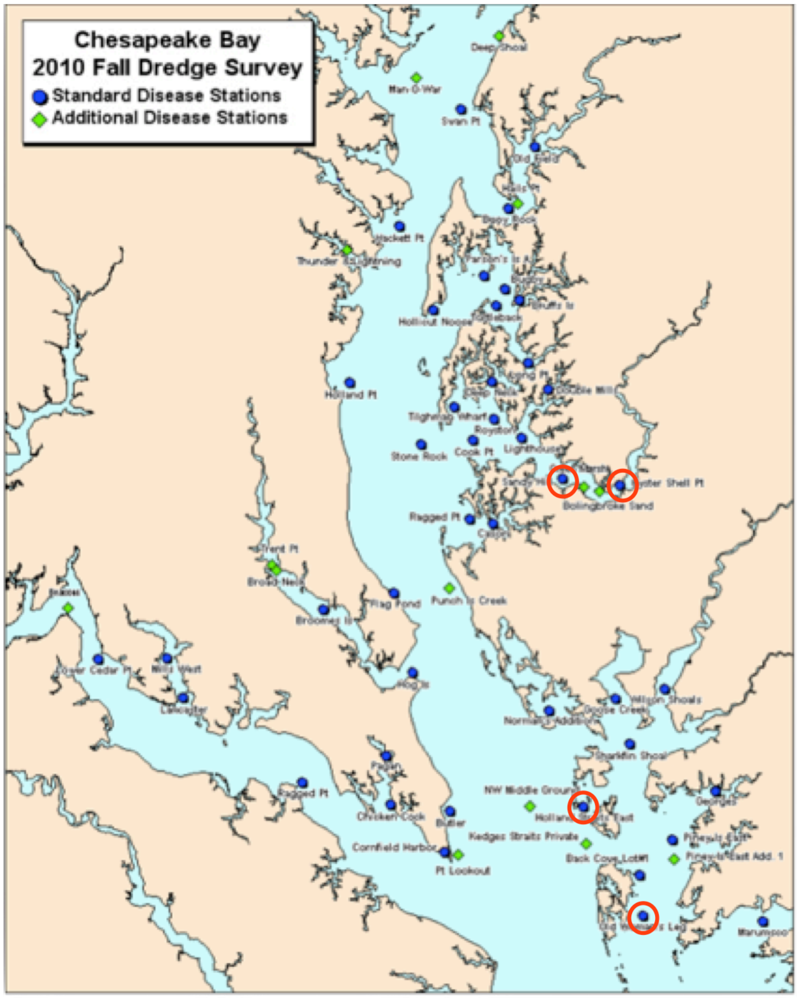

Figure 8. A map of the disease stations in the Chesapeake Bay monitored by the Maryland Department of Natural Resources. Four sites (circled in red) were sampled in October 2011. The two southern sites have historically high levels of Dermo infection, while the two middle sites have a lower prevalence of Dermo. Source: Tarnowski, M. Maryland Oyster Population Status Report: 2010 Fall Survey

Table 1. OTUs which were significantly associated with oysters (grey rows) or water (white rows) were identified by a G-Test of Independence.

O.T.U. #	G value	G prob. probability	Fraction Oyster Samples	Fraction Water Samples	Consensus Lineage
2398	29.71	1.59E-06	14/14	0/9	Tenacibaculum
934	19.65	0.0002	2/14	9/9	Unknown
3242	19.65	0.0002	12/14	0/9	Unknown
150	19.65	0.0002	2/14	9/9	Unknown
571	16.69	0.0008	11/14	0/9	Unknown
1715	14.42	0.0024	14/14	3/9	Vibrio
3779	14.23	0.0026	10/14	0/9	Terasakiella
2383	14.23	0.0026	10/14	0/9	Nitrospira
2074	14.23	0.0026	10/14	0/9	Flavobacteriaceae
1849	14.23	0.0026	4/14	9/9	Unknown
253	14.23	0.0026	10/14	0/9	Bacteroidetes
467	14.23	0.0026	10/14	0/9	Flavobacteriaceae
1360	14.23	0.0026	10/14	0/9	Terasakiella
1785	13.25	0.0041	12/14	1/9	Tenacibaculum
2069	13.25	0.0041	2/14	8/9	Haliscomenobacter

Quantifying the Role of Carbon Amount and Quality for Transport of Contaminants on Our Landscapes: A Watershed-Scale Model

Basic Information

Title:	Quantifying the Role of Carbon Amount and Quality for Transport of Contaminants on Our Landscapes: A Watershed-Scale Model
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Start Date:	3/1/2011
End Date:	2/28/2012
Funding Source:	104B
Congressional District:	At large
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Hydrogeochemistry, Nutrients
Descriptors:	None
Principal Investigators:	Shreeram P. Inamdar

Publications

1. Dhillon, G. and S. Inamdar, 2011, Quantifying the Relative Contributions of Particulate and Dissolved C to the Total Carbon Export from the Catchment: A Watershed Scale Model Progress Report, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 6 pages.
2. Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2 DWRC Spotlight on Graduate Research, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 7.
3. Dhillon, G. and S. Inamdar, 2012, Quantifying the Relative Contributions of Particulate and Dissolved C to the Total Carbon Export from the Catchment: A Watershed Scale Model Progress Report, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 21 pages.

Title - Quantifying the relative contributions of particulate and dissolved carbon to the total carbon export from the catchment: A Watershed scale assessment

Gurbir Singh Dhillon and Shreeram Inamdar

Background and Justification –

Sediments and organic carbon are known to be the efficient carriers of contaminants such as persistent organic pollutants (POP's) (Harrad, 2009; Luo et al, 2009), nutrients especially N & P (Walling, 1997; Heathwaite et al., 2005) metals (Citeau et al., 2005) as well as microbes or pathogens (Oliver et al., 2005, Harrod and Theurer, 2002). Total organic carbon (TOC), comprising dissolved organic carbon (DOC) and particulate organic carbon (POC), is an indicator of organic contamination of aquatic systems (Ni et al., 2008). Studies have reported a positive correlation between the TOC concentration and the content and degradation rates of organic contaminants such as PAH's (Hinga, 2003, Chen et al., 2005). Dissolved organic carbon (DOC) is considered as a sorbent and carrier for organic contaminants (Knabner et al., 1996) and can also increase the solubility and mobility of many metals and organic contaminants (Ouyang, 2003). Various studies such as McCarthy and Zachara, 1989 have reported DOC mediated enhanced transport of pesticides and hydrophobic organic chemicals in soils. Particulate forms also act as a carrier to transport organic chemicals (Ni et al., 2008) and are believed to be responsible for the export of hydrophobic contaminants (Luo et al., 2009). Since the knowledge of transport mechanisms velocity and pathways of contaminants is a major requirement for their amelioration (McCarthy and Zachara, 1989), it is important to understand the movement of their carriers such as POC and DOC through terrestrial and aquatic systems.

The transport of suspended sediments and organic carbon through streams and rivers plays an important role in global carbon cycling and the regional budgets of organic carbon entering the oceans (Meybeck, 1982, 1993; Robertson et al., 1996; Sarin et al., 2002). Cole et al., 2007 estimated that around 0.9 Pg y^{-1} of carbon is delivered from the inland waters to the oceans. However the magnitude and drivers of the carbon flux in the inland water systems such as streams, rivers and wetlands remain poorly understood (Cole et al., 2007). Since these systems represent a major pathway in the global carbon cycle, it is important to investigate the concentration and flux of the forms of carbon being transported out of these systems. Understanding DOC and POC losses and their impact on carbon budgets is also essential to meet the carbon sequestration targets in light of potential future climate changes (Pawson et al, 2008)

Riverine influx of sediments and carbon into the oceans impacts not only the coastal sediment budgets but also the ocean biogeochemistry and water quality (Milliman and Meade, 1983). TOC is an important factor in stream water quality (Ouyang, 2003). DOC is a strong complexing agent for many toxic metals such as iron, aluminum, zinc and mercury (Eshleman and Hemond, 1985, Driscoll et al., 1988). It can also form compounds such as carcinogenic trihalomethanes in chlorinated drinking water (Nokes et al., 1999). Decomposition of POC plays an important role in river water quality such as decreasing dissolved oxygen concentration and increasing biochemical oxygen demand (Ouyang, 2003). Sediments and organic carbon also play important ecological roles. Organic carbon is the primary source of energy for the aquatic organisms and macro invertebrates in the stream systems (Cummins, 1975, Cummins et al., 1983). Coarse particulate organic matter, such as leaf litter is believed to be the major source of energy in small headwater streams in forests (Fisher and Likens 1973; Sedell et al. 1974). The transport of sediments and colloids also leads to problems such as loss of soil productivity and siltation of river beds (Greig et al., 2005; Harrod and Theurer, 2002). Thus, the understanding of dynamics of suspended sediments and dissolved and particulate forms of carbon has environmental and ecological significance.

There is also a great degree of uncertainty about the relative contribution of DOC and POC to the total carbon export. In his review, Hope et al, 1994 reports varying DOC/POC ratios in different watershed systems ranging from 0.1 to 701. POC has historically been regarded as the minor component of aquatic organic carbon based on measurements in large rivers where DOC/TOC ratios were reported to be between 0.6 and 0.8 in lowland rivers and lower than 0.5

for highland river systems (Meybeck, 1982). However studies such as Fisher and Likens, 1973; Dawson et al., 2002; Coynel et al., 2005; Kim et al., 2010; Jung et al 2012 have reported high POC concentration and export exceeding those of DOC especially during high-discharge storm events in upland forested watersheds and small mountainous watershed systems. It is therefore important to further investigate and compare the concentration and export of DOC and POC in different watershed types and climates.

Objectives –

The purpose of this study was to investigate the relative contributions of particulate (POC) and dissolved forms of carbon (DOC) to the total carbon export from a forested catchment and to examine temporal variations in DOC and POC concentration and export from the catchment especially during storm events. This study specifically addressed the following questions:

1) What are the within-storm temporal patterns of POC concentration and how do they relate to the dissolved organic carbon (DOC)?
2) How is the particulate organic carbon (POC) and dissolved organic carbon (DOC) concentration influenced by storm event conditions (intensity and magnitude of precipitation, antecedent conditions)? How do the dissolved and particulate amounts of carbon vary seasonally?
3) What proportion of the total carbon export is constituted by dissolved and particulate forms of carbon? How do the concentrations and amounts of particulate and dissolved forms vary with catchment scale?
4) What are the sources of POC in the watershed?

Site Description and Methodology

The study catchment (12 ha) is located within the Fair Hill Natural Resources Management Area (NRMA) (39°42' N, 75°50' W) in Cecil County, MD (Figure 1, inset). This catchment has been intensively instrumented and studied as a part of an ongoing study (Inamdar et al., 2011, 2012). The catchment drains into the Big Elk creek which lies within the

Piedmont physiographic region and eventually drains into the Chesapeake Bay.Cecil County has a humid, continental climate with well-defined seasons. The maximum daily mean temperature (1971–2000) was 24.6°C (July) and the daily minimum was -0.6°C (January), with a mean annual temperature of 12.2°C. For this same period, mean annual precipitation in this region was 1231 mm with ~ 350 mm occurring as snowfall in winter (Maryland State Climatologist Office 2008). Late summer (August-September) tends to be the driest period of the year while late spring (April-May) is the wettest. Vegetation in the study catchment consists of deciduous forest with pasture along the catchment periphery. Dominant tree species are *Fagus grandifolia* (American beech),*Liriodendron tulipifera* (yellow poplar), and *Acer rubrum* (red maple) (Levia et al., 2010).

Hydrologic monitoring

Stream flow discharge was monitored at the outlet of the 12 ha catchment (Figure 1) using a 6-inch Parshall flume and water flow depths were recorded every 20 minutes using a Global Water (Inc.) logger and pressure transducer. Depth to groundwater (from the soil surface) was recorded at five locations (Figure 1) in the 12 ha catchment at 30-minute intervals using Global Water loggers (Inc.). Groundwater logging wells consisted of PVC pipes (5 cm diameter) ~2 m below the ground surface that were continuously slotted from a depth of 0.3 m below the soil surface. Precipitation and air temperature data was available at 5-minute frequency from a weather station located in the Fairhill NRMA, about 1000 m from the outlet of the 12 ha catchment. All data was collected over the period of September 2010- December 2011.

Water Sampling and Chemistry

Stream water samples were collected for a total of 14 storm events over a period of 16 months from September 2010- December 2011. Storm event sampling for stream water was performed using automated ISCO samplers which were installed at the outlets of the 12 ha catchment as well as the 79 ha catchment. The ISCO samplers were triggered to sample when the rainfall amount exceeded 2.54 mm in a one hour period. The ISCO samples were collected in the "non-uniform" program model with a sampling frequency that ranged from as low as 15 minutes on the hydrograph rising limb to 3 hours on the recession limb.

In addition to the stream water samples, soil sediment samples were collected from the potential sediment source sites throughout the watershed in July, 2010. Soil sediment samples were collected from eleven watershed sites that accounted for four watershed sediment sources – riparian wetlands, uplands, stream bed and stream bank (Figure 1). The samples were taken from A and B horizons at each site and each sample had one replicate.

Sample Processing and Chemical Analyses

All samples were collected in HDPE bottles, filtered through a 0.45 µm filter paper (Millipore, Inc.) within 24 hours of collection and stored in at 4°C. The particulate sample analysis was carried out in the UD soil testing laboratory. Particulate organic carbon (POC) and nitrogen (PON) concentration is determined using the Elementar TOC analyzer. Major cations (Al^{3+}, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cu^{2+}, Zn^{2+}) were determined using Thermo elemental inductively coupled plasma. The Biogeochemistry Laboratory at SUNY-ESF, NY, which is a participant in the USGS QA/QC program, performed the following analyses: pH using a pH meter; major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and silica (Si) using a Perkin-Elmer ICP-AEC Div 3300 instrument; anions (Cl^{-}, NO_3^{-},SO_4^{2-}) using a Dionex IC; NH_4^{+} with an autoanalyzer using the Berthelot Reaction followed by colorimetric analysis; total dissolved nitrogen (TDN) using the persulfate oxidation procedure (Ameel et al., 1993) followed by colorimetric analysison an autoanalyzer; and DOC using the Tekmar-Dohrmann Phoenix 8000 TOC analyzer.

Results -

A total of 14 events were recorded for the whole observation period of September 2010 – December 2011. 7 of these events were in summer, 3 in winter, 2 in spring and 2 in fall. Maximum discharge during the observed rainfall events varied from 0.07 -5.02 mm/hr. Table 1 summarizes all flood characteristics during the observed flood events and their antecedent conditions. Suspended sediment and organic carbon concentrations vary widely during the events. SS concentration varied from 0-15748.8 mg/ while POC concentration ranged between 0 -252.22 mg/l and DOC concentration ranged between 0-13.56 mg/l for all the events. The flow-weighted mean concentrations and the peak concentrations for all the events are provided in table 2.

SS, POC and DOC concentrations increased rapidly with stream flow discharge within an event and peaked around maximum discharge. This pattern was consistent under various hydrologic and seasonal conditions. However there were important differences within the DOC and POC temporal patterns within the events which allude to different sources and flow paths of these forms of carbon within the watershed. POC peaked on the rising limb of the discharge hydrograph except in event 10 where it peaked on the falling limb. DOC concentration peak was concurrent or just after the discharge peak in all the events except event 9 where it peaked on the rising limb (Figure 6).

Although DOC also showed a rapid increase with increase in discharge, POC values showed a larger increase during the peak flow and then rapidly fell back to initial values immediately after the discharge peak while DOC decreased gradually through the hydrograph recession. DOC values did not decline back to their pre-event values for most of the events while POC values were found to be equal to or less then their initial values towards the end of the events.

In case of events with multiple peaks, increase in POC concentration was disproportionately higher for the first peak compared to the subsequent peaks. This is especially evident in the events 2 , 9, 13 and 14 where the first discharge peak is lower than the second discharge peak but the corresponding POC concentration is higher in case of the first discharge peak (Figure 4,6 &7). This phenomenon was also observed in event 1 where the first discharge peak with low discharge (Q_{max} = 0.41 mm/hr) corresponds to very high POC concentration peak (POC_{max} = 148.1 mg/l) and a five-fold increase in discharge (Q_{max} = 1.93 mm/hr) in second discharge peak corresponds to a small increase in POC concentration (POC_{max}= 190.6 mg/l) (Figure 1). However, these observations were not repeated in event 5, where the increase in POC concentration was strongly correlated to discharge in both the discharge peaks and temporal pattern of POC was identical to discharge throughout the event (Figure 5). In case of DOC, the concentration followed the temporal pattern of discharge in all the events except event 13 where it behaved like POC and showed higher DOC concentration in response to smaller discharge peak at the start of the event (Figure 7)

The POC content of the soil sediments (measured as POC %) was also lower during the second peak compared to the first peak in case of multi-peaked events. In event 1, the flow-weighted mean POC % went down from 13.82 % during the first peak to 7.02 % during the second peak. In event 9, it went down from 9.33 % during the first peak to 3.08 % during the second peak.

DOC also showed a slight decrease in concentration at the peak stream flow discharge for the very large events – event 1, 8 and 9(Figure 1 & 6). These events had very high values of peak discharge ranging from 3.60 to 5.02 mm/hr. A similar phenomenon was also observed in event 4 (Q_{max} = 0.68 mm/hr) and event 13 (Q_{max} = 3.16 mm/hr) where the DOC concentration became static instead of increasing with discharge at the discharge peak.

6 successive rainfall events (Events 6 to 11) were recorded in a two month period (July 8, 2011 –Sept 8, 2011). The POC showed a gradual decrease in concentration despite the increase in discharge values in the successive events (Figure 8). Event 6 (July 8, 2011) recorded a maximum POC concentration of 183.7 mg l^{-1} for a corresponding maximum discharge of 0.48 mm/hr while Event 11 (September 6, 2011) recorded a maximum POC concentration of only 59.9 mg l^{-1} despite a much higher discharge of 4.19 mm/hr. These rainfall events also show a gradual impoverishment in the organic content of particulate matter from the first flood (POC = 8.72 %) to the last flood (POC = 0.26)

The results clearly demonstrated the seasonality in the concentration and export of POC and DOC (Table 5). The summer events had the highest concentration and export of POC and SS. The average flow-weighted concentration of POC was 70.3 mg/l in the summer events while in the spring, winter and fall events it was 10.2, 12.1 and 9.3 mg/l respectively. The highest DOC concentrations as well as loads were also recorded in the summer events.

The POC loads transported during the events were much higher compared to the DOC loads (Table 3). The POC loads in all the events varied from 1.1 -153.9 kg while the DOC loads varied from 0.1 to 39.1 kg. Overall, 453.7 kg of POC was exported while 99.9 kg of DOC was exported during the observed 13 flood events. The contribution of POC towards the total carbon export was higher than DOC in all of the storm events. Average % contribution of POC towards the total carbon export was 76.7% while DOC contributed 23.2% of the total C export. In summer events, the average % POC contribution increased up to 87.8%. Major portion of the carbon export took place towards the start of events on the rising limb (Table 4). While the rising limb accounted for an average of only 19.2% of the total event duration, it was responsible for 51.4% of the total carbon export. The role of rising limb was even more pronounced in case of the particulate carbon where it was responsible for 56.4% of the total export while in case of the dissolved form, it was responsible for 35.4% of the total export.

<u>Abstract for the DWRC website –</u>

A total of 14 storm events were evaluated over a 15-month period in a 12 ha forested catchment in the mid-Atlantic region of USA to determine the temporal variability in dissolved (DOC) and particulate organic carbon (POC) and to compare the relative contribution of DOC and POC to the total carbon export. The concentrations of DOC and POC both increased with storm-event discharge. However, the POC concentrations increased more rapidly resulting in higher concentrations of POC compared to DOC at peak stream discharge. POC was the dominant form of organic carbon export, accounting for 82% of the total organic carbon flux. The contribution of POC ranged from 61% to 91% of the total C export. Most of the carbon export occurred in the early part of the event with 51% of carbon exported on rising limb of the hydrograph which accounted for an average of only 19% of the total duration of the event. The amount of precipitation and the seasonal timing of the storm event were important factors controlling the exports of carbon. The summer events had the highest concentrations and exports for both POC and DOC. The three largest events were contributed to 72% and 63% of the exports of POC and DOC, respectively. The storm event POC-discharge relationships were generally clockwise while DOC-discharge relationships alternated between clockwise, anticlockwise and mixed patterns. These results highlight the importance of POC in the exports of carbon from watersheds during storm events. The differences in responses of DOC and POC

to the hydrologic events allude to the different sources and pathways of POC and DOC in the watershed.

Table 1: Hydrologic attributes for all the events recorded during the study period.

Event	Date	Season	Duration hrs	Precipitation			Streamflow Discharge				7-day GW depth[a]	
				Amount (mm)	Intensity (mm)	API7 (mm)	Amount (mm)	Peak mm/hr	RR	AR24hrs mm	LW2 (m)	LW5 (m)
1	9/30/2010	Su	61:15	154.90	5.2	20.3	13.54	3.69	0.09	0.19	0.29	0.77
2	12/1/2010	W	56:30	34.6	3.9	4.9	3.81	0.79	0.11	0.45	0.26	0.53
3	2/25/2011	W	62:16	21	1	10.3	6.69	0.54	0.32	0.68	0.13	N/A
4	3/10/2011	Sp	48:30	45.9	1.2	45.4	11.23	0.68	0.24	1.71	0.10	N/A
5	4/16/2011	Sp	30:00	37.7	1.2	23.7	7.06	1.16	0.19	1.31	0.05	0.43
6	7/8/2011	Su	19:45	23.4	5.4	3.7	0.81	0.48	0.03	0.20	0.14	0.66
7	7/28/2011	Su	7:00	2.2	1.2	0.7	0.13	0.07	0.06	0.11	0.19	0.71
8	8/9/2011	Su	14:30	21	6.5	7.2	0.50	0.36	0.02	0.61	0.21	0.74
9	8/14/2011	Su	30:45	101.2	4.9	33.3	9.00	3.60	0.09	8.709	0.21	0.72
10	8/27/2011	Su	59:00	155.5	3.6	17.3	32.67	5.02	0.21	22.31	0.20	0.55
11	9/6/2011	Su	44:00	101.8	4.1	9.4	16.47	4.19	0.16	1.69	0.16	0.40
12	11/16/2011	F	40:15	13.4	0.8	5.5	2.03	0.10	0.15	1.65	0.04	0.47
13	11/23/2011	F	84:15	52.4	3.6	26.6	16.14	3.16	0.31	1.11	0.04	0.46
14	12/23/2011	W	48:00	34.8	1.8	2	9.50	2.04	0.27	1.30	-0.01	0.41

[a] Su – Summer; W- Winter: Sp – Spring; F- Fall; API7 – 7-day antecedent precipitation preceding the event; RR – runoff ratio – ratio of discharge amount and total precipitation for event; AQ24hr – average discharge for 24 hrs prior to event; 7-day groundwater depth – average of groundwater depth for 7 days preceding the event; N/A - data not available.

Table 2: Flow weighted means and peak values of SS, POC and DOC for all the events.

	SSC (mg/l)		POC (mg/l)		DOC (mg/l)	
	Mean	Maximum	Mean	Maximum	Mean	Maximum
9/30/2010	801.7	2330.4	67.8	190.6	8.2	11.2
12/2/2010	3306.5	14389.5	16.1	88.3	6.1	10.8
2/25/2011	982.0	2702.2	8.5	23.4	3.8	6.5
3/10/2011	418.5	1113.2	5.8	15.5	3.3	5.1
4/16/2011	560.2	3356.3	14.5	93.7	5.4	8.4
7/8/2011	653.7	2042.2	58.4	183.7	9.5	13.6
7/28/2011	5743.8	14576.0	78.8	151.9	7.3	10.4
8/9/2011	1366.1	2310.0	112.1	252.2	9.0	11.9
8/14/2011	2910.8	6054.8	103.2	223.7	10.2	18.3
8/28/2011	1301.2	2274.5	40.0	69.8	10.0	11.9
9/6/2011	6891.6	12903.5	32.0	59.9	N/A	N/A
11/16/2011	546.7	2266.4	5.3	21.8	3.3	5.1
11/23/2011	4915.9	15748.8	13.3	60.8	7.5	10.8
12/23/2011	2596.1	10376.6	11.6	46.4	5.3	10.5

Table 3: SS, POC, DOC loads and their percent contribution to total C export in all the events recorded during the study period.

Date	SS (kg)	POC (kg)	DOC (kg)	TOC (kg)	POC %	DOC %
9/30/2010	1296.8	108.2	13.2	121.4	89.1	10.9
12/2/2010	1349.9	6.5	2.6	9.1	71.7	28.3
2/25/2011	769.7	6.7	2.9	9.6	69.7	30.3
3/10/2011	553.1	7.7	4.6	12.3	62.8	37.2
4/16/2011	517.4	13.1	4.4	17.4	74.9	25.1
7/8/2011	52.1	4.6	0.8	5.4	84.4	15.6
7/28/2011	79.8	1.1	0.1	1.2	91.0	9.0
8/9/2011	73.2	5.7	0.5	6.2	91.5	8.5
8/14/2011	3118.2	108.0	10.8	118.8	90.9	9.1
8/28/2011	5017.6	154.0	39.2	193.1	79.7	20.3
9/6/2011	13393.9	62.2	N/A	N/A	N/A	N/A
11/16/2011	131.0	1.3	0.8	2.1	61.3	38.7
11/23/2011	9057.0	24.5	14.3	38.8	63.2	36.8
12/23/2011	2783.3	12.4	5.8	18.3	68.1	31.9

Table 4: Export of POC, DOC and TOC on rising and falling limbs in all the events.

Event	Time (hours)			POC (kg)			DOC (kg)			TOC (kg)		
	RL	FL	% RL	RL	FL	% RL	RL	FL	% RL	RL	FL	% RL
9/30/2011	14:15	48:30	22.7	81.9	26.3	75.7	5.7	7.5	43.4	87.7	33.8	72.2
12/2/2010	15:00	41:30	26.5	5.0	1.5	76.8	1.4	1.2	53.8	6.4	2.7	70.3
2/25/2011	20:45	41:31	33.3	3.4	3.3	50.2	1.1	1.9	35.1	4.4	5.3	45.5
3/10/2011	11:45	36:45	24.2	4.0	3.7	51.9	1.2	3.5	25.9	5.2	7.2	42.1
4/16/2011	8:30	21:30	28.3	9.0	4.1	68.6	1.2	3.2	27.1	10.2	7.3	58.2
7/8/2011	0:30	19:15	2.5	2.3	2.3	50.5	0.1	0.7	17.6	2.5	3.0	45.4
7/28/2011	1:30	5:30	21.4	0.8	0.4	68.2	0.0	0.1	44.9	0.8	0.4	66.1
8/9/2011	2:00	12:30	13.8	3.8	1.9	66.9	0.3	0.3	47.6	4.1	2.2	65.3
8/14/2011	4:00	26:45	13.0	61.8	46.2	57.2	5.9	4.9	54.6	67.7	51.1	57.0
8/28/2011	11:30	47:30	19.5	40.0	114.0	26.0	12.9	26.3	32.9	52.9	140.3	27.4
11/16/2011	4:00	36:15	9.9	0.4	0.8	34.9	0.1	0.7	11.5	0.5	1.5	25.9
11/23/2011	19:30	64:45	23.1	14.5	10.0	59.3	4.8	9.5	33.5	19.3	19.5	49.8
12/23/2011	5:00	43:00	10.4	5.9	6.6	47.2	1.9	3.9	32.4	7.8	10.5	42.5

Table 5: Flow weighted means, peak values and mean exports of SS, POC and DOC for all seasons.

	SSCm (mg/l)	SSCmax (mg/l)	SSCt (kg)	POCm (mg/l)	POCmax (mg/l)	POCt (kg)	DOCm (mg/l)	DOCmax (mg/l)	DOCt (kg)	TOCt (kg)
Fall	2731.3	15748.8	**4594.0**	9.3	60.8	12.9	5.4	10.8	7.5	20.4
Spring	489.4	3356.3	535.3	10.2	93.7	10.4	4.4	8.4	4.5	14.9
Summer	**2809.8**	**19363.7**	3290.2	**70.3**	**252.2**	**63.4**	**9.0**	**18.3**	**10.8**	**74.4**
Winter	2294.9	14389.5	1634.3	12.1	88.3	8.5	5.1	10.8	3.8	12.3

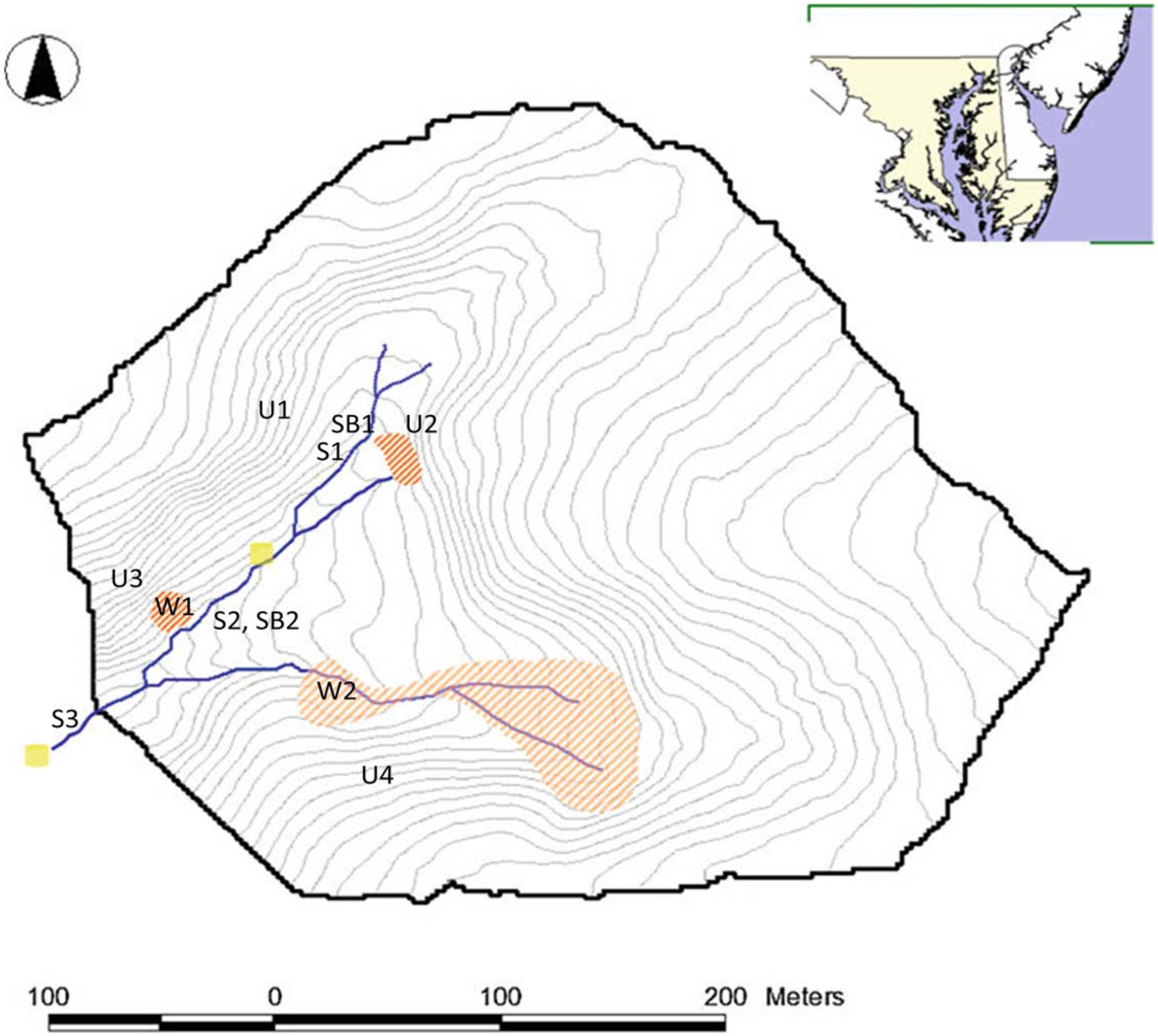


Figure 1: Sampling locations for the soil sediment samples in the 12 ha catchment (ST3)

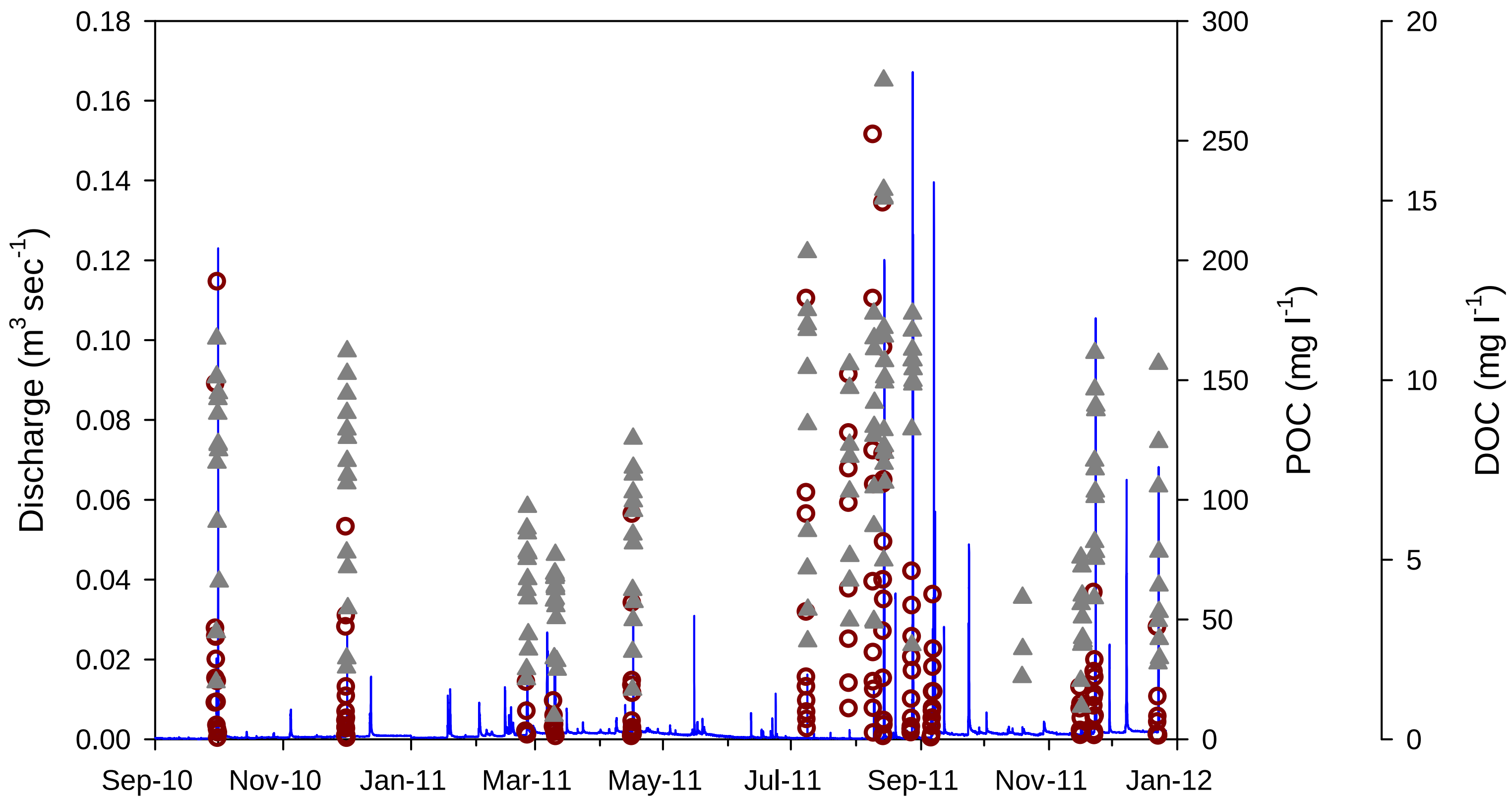


Figure 2: Temporal variability in particulate (POC) and dissolved (DOC) organic carbon during the whole study period (September 2010 – December 2011)

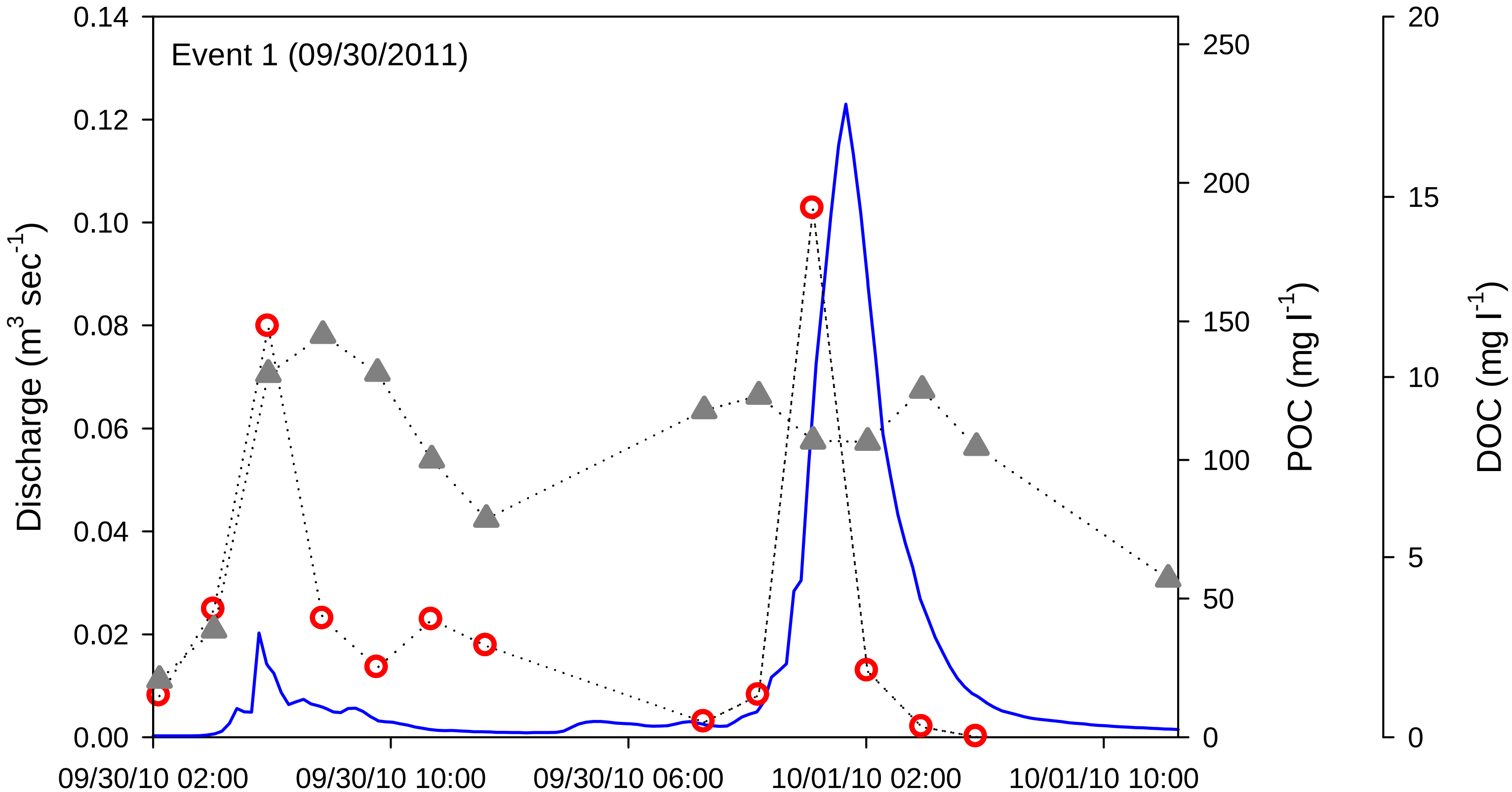


Figure 3: Stream flow, POC and DOC concentrations for the event of September 30, 2010 for catchment ST3

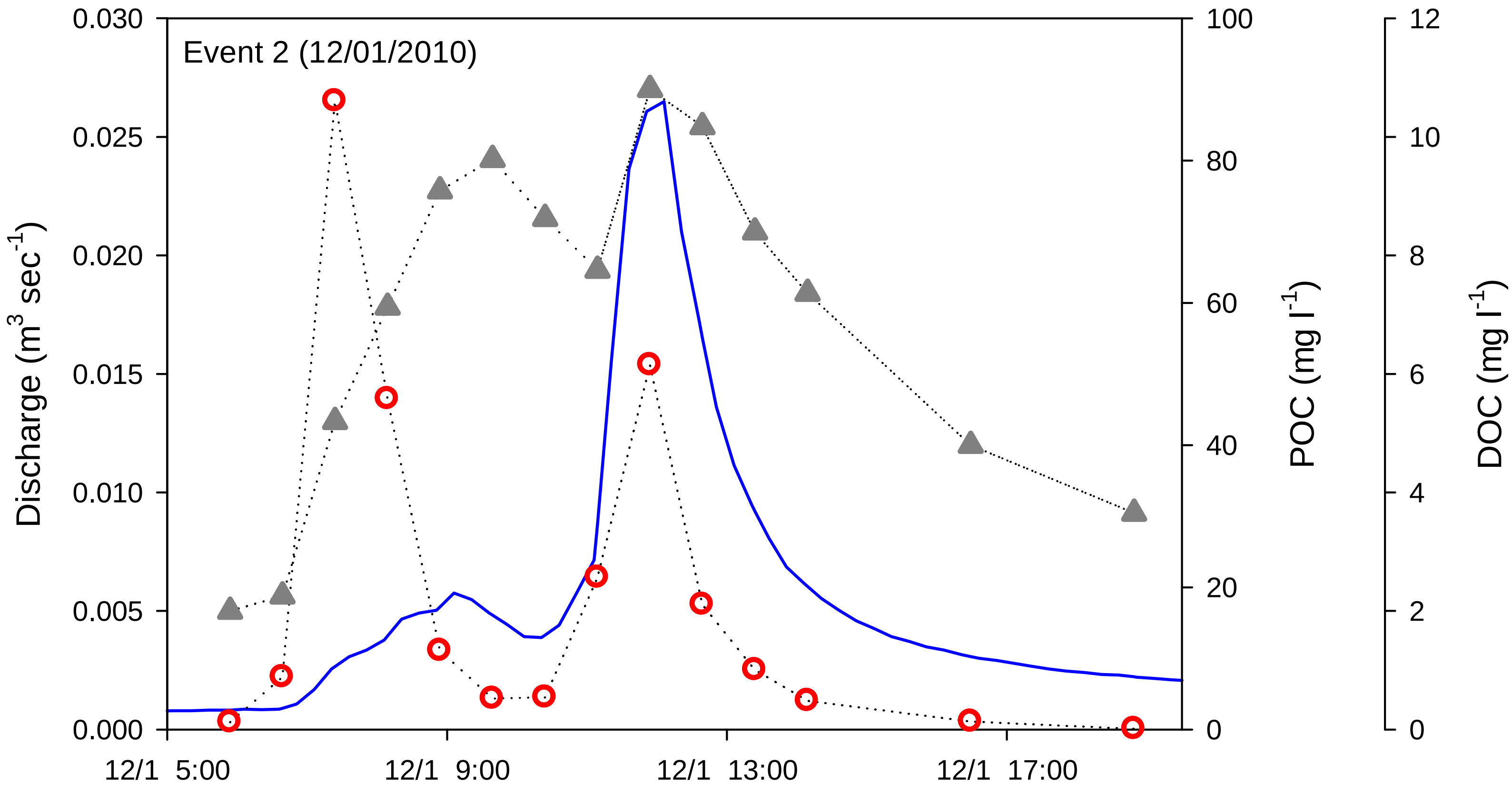


Figure 4: Stream flow, POC and DOC concentrations for the event of December 1, 2010 for catchment ST3

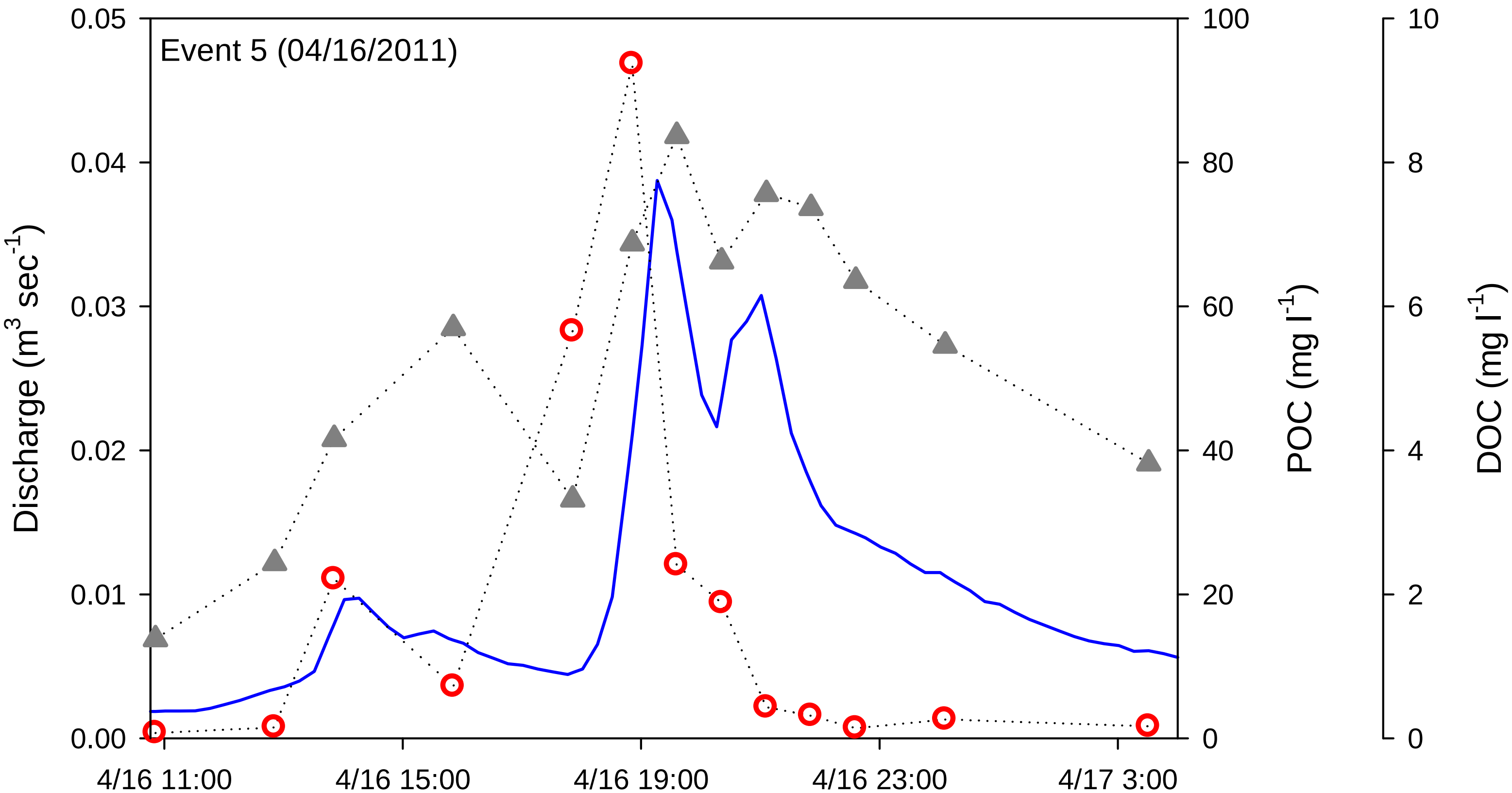


Figure 5: Stream flow, POC and DOC concentrations for the event of April 16, 2011 for catchment ST3

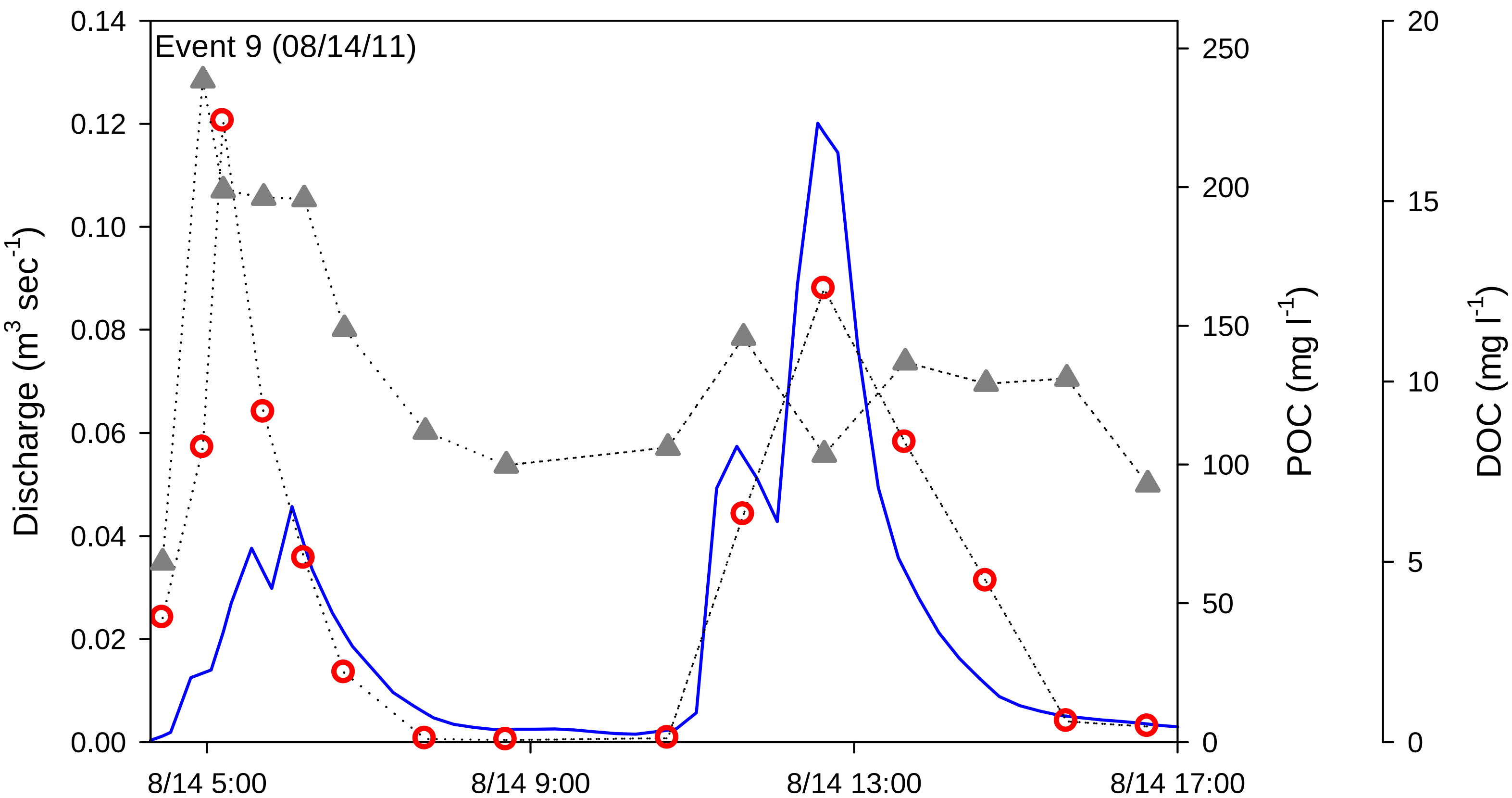


Figure 6: Stream flow, POC and DOC concentrations for the event of August 14, 2011 for catchment ST3

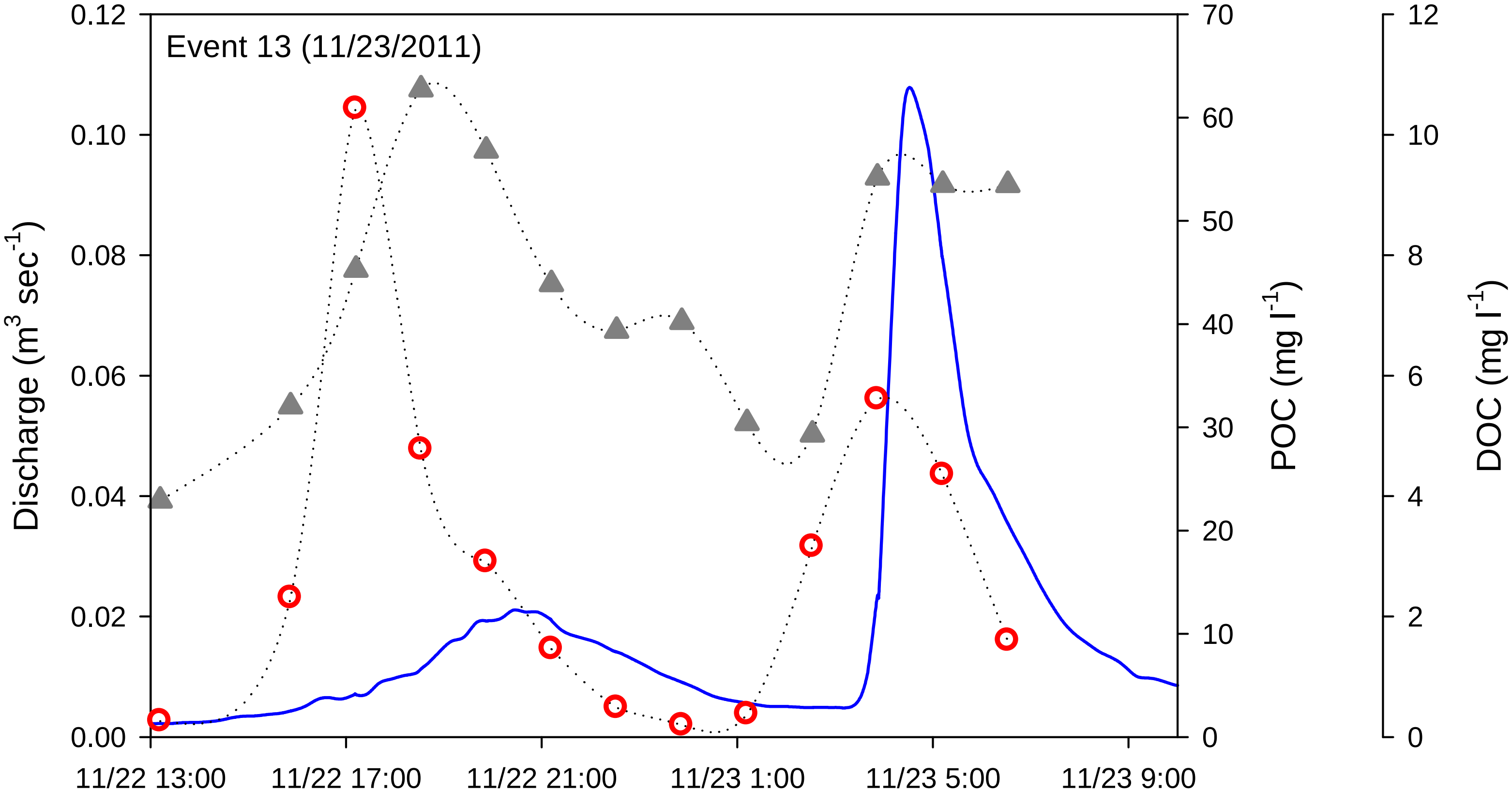


Figure 7: Stream flow, POC and DOC concentrations for the event of November 23, 2011 for catchment ST3

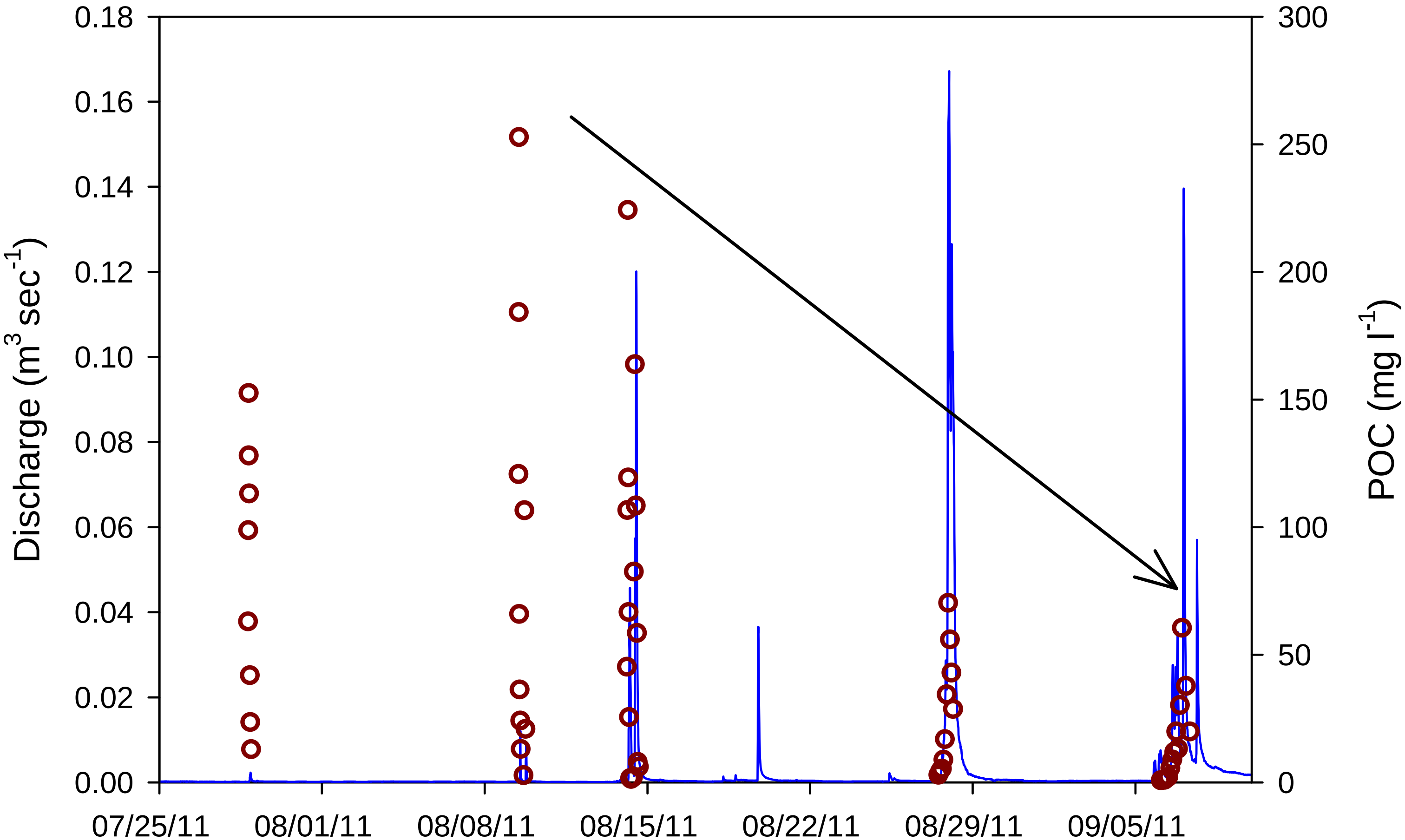


Figure 8: Successive events (events 8 -11) showing decrease in POC concentration despite increase in the discharge.

Sediment Transport through Historic Mill Dams of the Christina River Basin

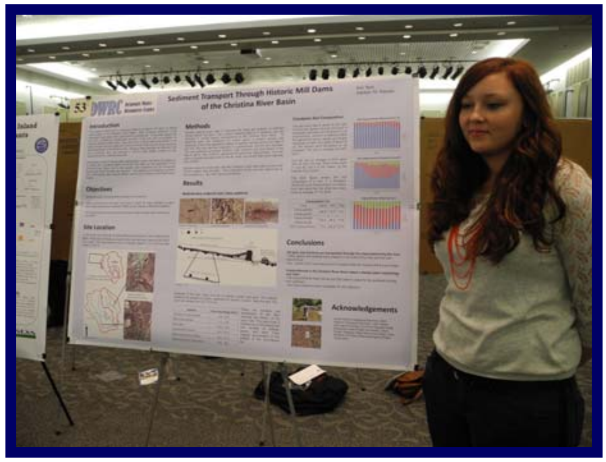
Basic Information

Title:	Sediment Transport through Historic Mill Dams of the Christina River Basin
Project Number:	2011DE206B
Start Date:	3/1/2011
End Date:	2/28/2012
Funding Source:	104B
Congressional District:	At Large
Research Category:	Climate and Hydrologic Processes
Focus Category:	Sediments, Surface Water, Water Quality
Descriptors:	None
Principal Investigators:	James Pizzuto, Kimberly Teoli

Publications

1. Teoli, K., and J. Pizzuto. 2012. Sediment Transport through Historic Mill Dams of the Christina River Basin. Delaware Water Resources Center, University of Delaware, Newark, Delaware, 6 pages.
2. Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2 Introducing Our 2011-12 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 6.

Undergraduate Internship Project #1 of 8 for FY11



Intern ***Kimberly Teoli's*** project, sponsored by the ***DWRC***, was titled "Sediment Transport through Historic Mill Dams of the Christina River Basin." She was advised by Dr. James Pizzuto of the ***UD's*** Department of Geological Sciences.

Abstract

The study explores the temporal and spatial effects of historic run-of-river dams in the Christina River Basin. The objective of this study was to determine if sediment accumulates to facilitate the transport of bed material from upstream through the impoundment, at steady-state, without net deposition. It also aims to determine if run-of-the-river mill dams accumulate sedimentary materials of differing size classes in distinctive patterns after they have been in place for many decades. Methods included surveying, grain size analysis, and wet sieving techniques. Our results showed that sediment of all grain sizes were present both upstream and downstream of the dam. Generally, the dam is immediately followed by a scour hole lined with boulders, which is proceeded by a mid-channel bar. It was determined that the volume of the mid-channel bar is greater than the volume of the scour hole. In conclusion, bed material of all grain size fractions are being transported through the impoundment. Over time, a steady state is reached in the impoundment, without net deposition. The impoundment also appeared to influence soil composition in the affected floodplain.

Predation of Bacteria by the White Rot Fungi, Pleurotus ostreatus

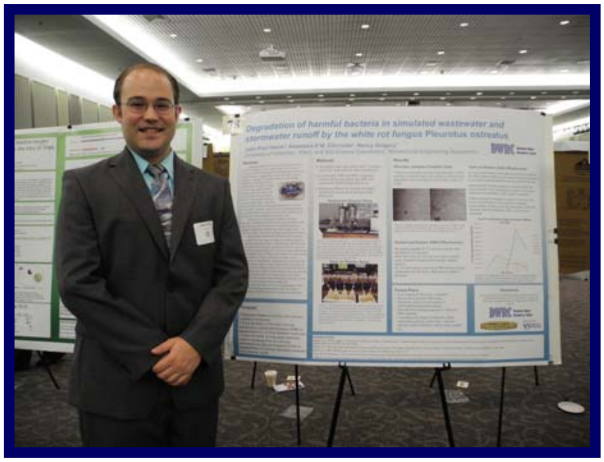
Basic Information

Title:	Predation of Bacteria by the White Rot Fungi, Pleurotus ostreatus
Project Number:	2011DE208B
Start Date:	3/1/2011
End Date:	2/28/2012
Funding Source:	104B
Congressional District:	At large
Research Category:	Water Quality
Focus Category:	Wastewater, Water Quality, Treatment
Descriptors:	None
Principal Investigators:	Anastasia Chirnside, John Paul Harris

Publications

1. Harris, J.P., and A. Chirnside. 2012. Predation of Bacteria by the White Rot Fungi, Pleurotus ostreatus. Delaware Water Resources Center, University of Delaware, Newark, Delaware, 51 pages.
2. Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2 Introducing Our 2011-12 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 6.

<u>Undergraduate Internship Project #2 of 8 for FY11</u>



Intern ***John Paul Harris'*** project, sponsored by the ***DWRC*** and the ***UD's College of Agriculture and Natural Resources,*** was titled "Predation of Bacteria by the White Rot Fungi, *Pleurotus ostreatus*." He was advised by Dr. Anastasia Chirnside of the ***UD's*** Department of Bioresources Engineering.

<u>Abstract</u>

Microbial pollutants from non-point sources are a common problem in many watersheds over the world. Current methods for dealing with these pollutants are limited and recent literature suggests that one of the most common solutions, vegetative or riparian buffers, while initially effective in removing harmful bacteria from runoff have been found to accumulate coliform bacteria over time. Due to the fact that within those systems there is no intentional mode of bacterial degradation, over time these bacteria subsequently get released back into the environment. However, research in an unrelated field has shown that certain fungi such as *Pleurotus ostreatus* will actively seek out and degrade bacteria *in situ*.

Capitalizing on that fact, the white rot fungus *P. ostreatus* was analyzed as a potential biocontrol agent used to reduce the amount of coliform bacteria in simulated wastewater (SWW) and storm water runoff. On water agar plates, *P. ostreatus* was seen to actively search out bacterial colonies, invade them, and consume them within 72 hours. Based on this principle, biocell reactors (BCR) were used to determine the effectiveness of spent mushroom compost (SMC) containing *P. ostreatus* to reduce the concentration of *Escherichia coli* in simulated wastewater and stormwater runoff. Loading was based on a 2" rainfall event over 24 hours at a fixed contamination level (bacterial concentration of 1 x 10^4 cells/mL). Overall *E. coli* concentrations in the effluent of the reactors containing live compost showed higher *E. coli* concentrations compared to the dead controls during the first 24 hours. After the first 12 hours however, the overall concentrations in the live reactors began to decrease while the concentration in the dead control began to increase. After allowing the reactors to rest for 24 hours and simulating a subsequent uncontaminated rain event, the *E. coli* concentration in the dead controls increased exponentially while the overall concentrations in the live reactors continued to decrease. The simulated wastewater effluent treatments, while having the lowest total concentration of *E. coli*, did not decrease over time. This suggests that the presence of the live fungus kills the adsorbed *E. coli* and that nutrient concentrations may play a significant role in the level of predation observed.

Oyster Gardening in Delaware Inland Bays: Filtration as a Means to Remove Excess Nitrogen

Basic Information

Title:	Oyster Gardening in Delaware Inland Bays: Filtration as a Means to Remove Excess Nitrogen
Project Number:	2011DE209B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	At large
Research Category:	Water Quality
Focus Category:	Water Quality, Nutrients, Non Point Pollution
Descriptors:	None
Principal Investigators:	Gulnihal Ozbay, Amy Cannon

Publications

1. Cannon, A., and G. Ozbay. 2012. Oyster Gardening in Delaware Inland Bays: Filtration as a Means to Remove Excess Nitrogen from Local Wastewater Treatment Plant Discharges. Delaware Water Resources Center, University of Delaware, Newark, Delaware, 10 pages.
2. Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2 Introducing Our 2011-12 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 6.

Undergraduate Internship Project #3 of 8 for FY11

Intern ***Amy Cannon's*** project, sponsored by the ***DWRC*** and the ***UD's College of Agriculture and Natural Resources,*** was titled "Oyster Gardening in Delaware Inland Bays: Filtration as a Means to Remove Excess Nitrogen." She was advised by Dr. Gulnihal Ozbay of ***Delaware State University's*** Department of Agriculture and Natural Resources.

"Before this research experience, I was only a beginner. I wanted to be a scientist, but I didn't quite feel like one yet. Although I certainly do not claim to be one yet, I am definitely a lot closer now. There were challenges, there were difficulties; yet they all served to teach me how to think anew about how to turn the challenges and difficulties into opportunities, and also how to tackle the next challenge. I had knowledge before this program, and now I have experience. It is like football and baseball or apples and oranges. Learning in the classroom is nothing like learning in the field and in the lab. Thank you, DWRC, for teaching me real life applications on how to be a scientist. You have made my dreams begin to take shape into reality, and for that experience, I will be forever grateful.

I learned that choosing a research location can be difficult unless a site visit takes place. This helps to ensure that the location is exactly what is needed to perform the task at hand. I have learned that taking larger water samples than required for testing is crucial in case you run out of a sample while testing them in the lab for any reason. I have learned that the weather can slow down activities that were planned, so plenty of time should be allocated for these kinds of changes. I have also learned how important it is to have a good plan, to organize your time well enough so that everything gets done in a timely manner, with no mistakes, and with plenty of time to fix any mistakes that may happen due to unforeseen circumstances. Expect the unexpected. And enjoy every moment, because this was a wonderful experience and I highly recommend it to anyone who wishes to become a serious scientist." – Amy Cannon

Abstract

The National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Mussel Watch Report shows Delaware with regionally high levels of cadmium and medium levels of lead in the Delaware Bay. Data from this report, as well as the United States Geological Survey (USGS) showing waste water treatment plants as a source for heavy metals, gave reason to start this project. Recent data indicate that adverse health effects of cadmium exposure may occur at lower exposure levels than previously anticipated, primarily in the form of kidney damage. The United States Environmental Protection Agency (USEPA) states: lead can result in physical and mental developmental delays in children and kidney problems in adults. Considering health risks associated with heavy metals in drinking water, a closer look at metals in this setting offers insight to potential threats as well as solutions. A point source was chosen near the Delaware Inland Bays to observe and record the state of the waterway's well-being in regards to heavy metals and other aquatic health concerns. Samples are being collected using EPA Method 1669 protocols and heavy metals being measured are cadmium and lead. Physical

and chemical water quality parameters are being measured bi-weekly and continuously since June 2011 using YSI instruments and protocols, and they include the following: temperature, total dissolved solids, salinity, dissolved oxygen, pH, turbidity, and nutrients. One sample location is directly at the mouth of the discharge, three other locations are proximate to the discharge, and one control location is approximately 650 meters away. Aquatic health data in regards to nutrients show extremely high levels of nitrogen and phosphorus, limiting nutrients. These high levels can cause ecosystem stress, hypoxia and eutrophication. A resolution to move the discharge out to the ocean by the end of 2013 has been reached by the State of Delaware. Data currently being examined to see if a relationship exists between levels of heavy metals and proximity to the point source show the opposite effect is true. The levels of heavy metals are lowest at the point source, and highest at the control location that is farthest away from the wastewater effluent. It is the new hypothesis that the other point source in the Delaware Inland Bays, a coal-burning energy plant, is causing these results. It is planned to add a new location in the Indian River Bay, near this energy plant, to test this new hypothesis. These data will help to improve the understanding of this ecosystem, as well as determine if this is a healthy habitat to sustain resilient and thriving marine resources and communities. In addition, potential for future research is possible if support is shown for the new hypothesis.

Characterization of Submarine Groundwater Discharge Sites in a Coastal Lagoon

Basic Information

Title:	Characterization of Submarine Groundwater Discharge Sites in a Coastal Lagoon
Project Number:	2011DE210B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	At large
Research Category:	Climate and Hydrologic Processes
Focus Category:	Groundwater, Non Point Pollution, Nitrate Contamination
Descriptors:	None
Principal Investigators:	Alan Scott Andres, Stephen Gonski

Publication

1. Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2 Introducing Our 2011-12 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 6.

Undergraduate Internship Project #4 of 8 for FY11

Intern ***Stephen Gonski's*** project, co-sponsored by the ***DWRC*** and the ***Delaware Geological Survey*** was titled "Characterization of Submarine Groundwater Discharge Sites in a Coastal Lagoon." He was advised by Mr. A. Scott Andres of the Delaware Geological Survey.

Abstract

The biogeochemical characterization of submarine groundwater discharge sites along the Indian River Bay in southern Delaware has been and continues to be an essential step in the completion of the tasks associated with the Geochemistry and Resistivity components of the Submarine Groundwater Discharge (SGD) Project that is currently being conducted by the Delaware Geological Survey and the University of Delaware's Department of Geological Sciences. The biogeochemical characterizations often involve nitrogen in some capacity, as it is a nutrient that can bring either sustained growth or destruction to estuarine ecosystems like those of the Indian River Bay. In conjunction with the protocol of the SGD Project governing the treatment of nitrogen, the denitrification potential at various submarine groundwater sites was gauged, so that these sites could be targeted for future, more comprehensive studies. More specifically, an investigation of denitrification potential in groundwater was performed to assist in the assessment of the validity of Hypothesis H3 of the SGD Project.

The investigation of groundwater denitrification potential was three-tiered, in the respect that it required groundwater sampling, laboratory analysis, and data analysis. Samples were taken from various on-shore monitoring wells and off-shore CMT sites at Holts Landing State Park in August 2011. Relevant data including temperature, conductivity, pH, and ORP were collected at that time. These samples were then analyzed for dissolved N2/Ar and O2/Ar ratios using membrane inlet mass spectrometry (MIMS). The data collected at the time of sampling and the dissolved gas ratios were utilized in the quantification of excess N2 gas. A presence of excess N2 gas can be considered evidence of denitrification. Additionally, the O2 saturation was also determined. A low O2 saturation is characteristic of denitrifying conditions.

It was found that the results of this project were inconclusive. After the completion of the data analysis, notable inconsistencies, often very large ones, in the yielded excess N2 gas and O2 saturation were observed between both samples of the same well and the individual wells themselves. These inconsistencies were attributed to sources of error that were discovered after the completion of the project, the biggest of which was found to be the scintillation vials that were made available for use for this experiment. The magnitude of the variance observed between the triplicate samples taken from the same wells ranged from 1.5-2.5%, which is much greater than the 0.03% needed for groundwater denitrification studies (Kana et al., 1994). Because of these inconsistent results, none of the SGD sites sampled could be classified as having high denitrification potential.

In the context of the SGD Project, studies like these are one of the preliminary steps in understanding the fate of the nitrate entering the Indian River Bay via SGD. When done properly with the right equipment, similar studies can help identify SGD sites that have high denitrification potential. In the end, these SGD sites can be tapped for future studies involving nitrogen isotopes that can quantify denitrification rates and estimate a SGD-corrected nitrate flux into the Indian River Bay.

Hydraulic Properties of the Columbia Aquifer

Basic Information

Title:	Hydraulic Properties of the Columbia Aquifer
Project Number:	2011DE211B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	At large
Research Category:	Climate and Hydrologic Processes
Focus Category:	Groundwater, Hydrology, Geomorphological Processes
Descriptors:	None
Principal Investigators:	Alan Scott Andres, Nicholas Spalt

Publications

1. Spalt, N., and A. Andres. 2012. Hydraulic Properties of the Columbia Aquifer. Delaware Water Resources Center, University of Delaware, Newark, Delaware, 12 pages.
2. Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2 Introducing Our 2011-12 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 6.

Undergraduate Internship Project #5 of 8 for FY11

Intern ***Nicholas Spalt's*** project, co-sponsored by the ***DWRC*** and the ***Delaware Geological Survey*** was titled "Hydraulic Properties of the Columbia Aquifer." He was advised by Mr. A. Scott Andres of the Delaware Geological Survey.

"The DWRC internship has been an incredibly rewarding experience. Prior to the internship, I had little field experience with hydrogeology, but over the summer I acquired skills including the construction of wells and aquifer-response testing. After working with my advisor, Scott Andres, I discovered my interest in this field of geology and I will now pursue a career in it. This is a great program for young scientists to develop their career objectives, and come out with skills to make them marketable in the world of employment." – Nicholas Spalt

Abstract

Lithologic and hydraulic characteristics of a given area are key factors controlling groundwater supply potential, wastewater disposal, and the harboring of contaminants. This report is intended to correlate lithologies of the aforementioned area to hydraulic properties, specifically hydraulic conductivity (K).

Lithologic and hydrologic data from more than 20 wells ranging in depths from tens to hundreds of feet in this study were evaluated. Lithologic data were collected during well installation, while hydrologic data were observed in this study. K values from lithologic data were compared to tests using the Bouwer/Rice and Butler methodologies. Comparison of the information is important in determining the usefulness in establishing a model to interpret hydraulic conductivities by sediment grain size, type, and sorting. Based on the results, this model could not be applied more generally to use residential and commercial driller logs to identify possible wastewater disposal systems or water resource supply.

This report describes a MODFLOW experiment in which a steady state, three dimensional, homogeneous flow model was used to calculate flow direction and head levels. MT3DMS was used to simulate transport for solutes common with solid waste of the area, considering variable sorption and hydrodynamic dispersion for different compounds.

Spatio-Temporal Hydrodynamic Variability in a Small Tidal Creek: DNERR St. Jones Reserve

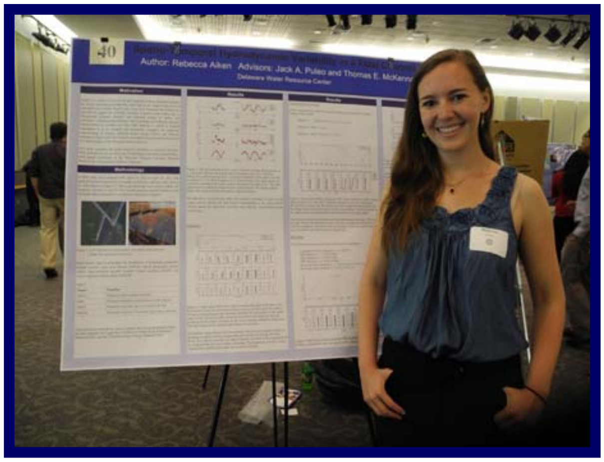
Basic Information

Title:	Spatio-Temporal Hydrodynamic Variability in a Small Tidal Creek: DNERR St. Jones Reserve
Project Number:	2011DE212B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	At large
Research Category:	Climate and Hydrologic Processes
Focus Category:	Wetlands, Hydrology, Ecology
Descriptors:	None
Principal Investigators:	Jack Puleo, Rebecca Aiken, Thomas McKenna

Publications

1. Aiken, R., J. Puleo, and T. McKenna. 2012. Spatio-Temporal Hydrodynamic Variability in a Small Tidal Creek: DNERR St. Jones Reserve. Delaware Water Resources Center, University of Delaware, Newark, Delaware, 39 pages.
2. Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2 Introducing Our 2011-12 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 6.

Undergraduate Internship Project #6 of 8 for FY11



Intern ***Rebecca Aiken's*** project, co-sponsored by the ***DWRC*** and the ***UD's College of Earth, Ocean, and Environment***, was titled "Patio-Temporal Variability in a Small Tidal Creek: DNERR St. Jones Reserve." She was advised by Dr. Jack Polio of the ***UD's*** Department of Civil and Environmental Engineering and Dr. Tom McKenna of the Delaware Geological Survey.

Abstract

The purpose of this study is to quantify the forcing parameters, namely the three-dimensional velocities, turbulent kinetic energy, and stresses, within a tidal channel and explore the effectiveness of in-situ measurements to quantify fundamental hydrologic characteristics. Three methods of analysis are implemented to quantify these characteristics: the Logarithmic Profile Method (LP), the Covariance Method (COV), and the Turbulent Kinetic Energy Method (TKE).

A field study was conducted at St. Jones Reserve in Dover, DE from April 14, 2011 to April 18, 2011. At the analyzed location in St. Jones Reserve, a tertiary saltwater tidal creek intersected a secondary tidal creek Equipment was deployed at three locations in the channels with two sensor rigs in the secondary channel and one in the tertiary tidal channel to measure changes caused by interaction between the water bodies and variations in hydrologic characteristics. Sensors were placed in the center of the channels to determine the distribution of sediment suspension and velocity. Field sensors used to investigate the distribution of hydrologic parameters include acoustic water level sensors (AWLS) to ascertain data on free surface elevations, optical backscatter sensors (OBS) to determine sediment concentrations, high-resolution acoustic Doppler Current profilers (ADCP) to measure near bed velocity profiles up to 3cm above the bed, and electro-magnetic current meters (EMCM) to assess velocities higher in the water column. Sample recordings were collected in closely spaced time intervals, allowing for an accurate understanding of hydrologic changes during tidal cycles.

The study shows an oscillating tidal cycle resulting in asymmetric velocities and creating two velocity peaks during the tidal cycle: one during ebb and one during flood. The velocity peak during ebb is larger than the one during flood. Additionally, analysis of the three-dimensional velocity profile shows that the along-stream (x direction) and cross-stream (y direction) velocities are approximately three times larger than the vertical (z direction) velocities, making them the primary contributors to the other forcing parameters. In conjunction with the maximum along-stream and cross-stream velocity peaks, fluxes of suspended sediment occurred.

Analysis of the methods to compute the forcing parameters shows that not all methods provide equally accurate results for near bed computations. In general, methods utilizing all velocity components provide the best, most accurate calculation for TKE of the system. In general, the

best method to compute bed stress is the logarithmic profile method. The average bed stress computed throughout the tidal cycle using the LP method is most nearly reflected by the results obtained using the stress computed using only the vertical velocity component. The peaks in the forcing parameters coincide with increased elevations of sediment suspension, indicating that these parameters drive erosion within the channel.

In conclusion, levels of erosion increase when the peak velocities, turbulent kinetic energy, and bed stress occur. The most accurate methods to compute the turbulent kinetic energy of the system include three velocity components, while the logarithmic profile method provides the best method to calculate the bed stress within the system.

Is Atmospheric Deposition and Washoff of Aluminum in Stemflow a Significant Source

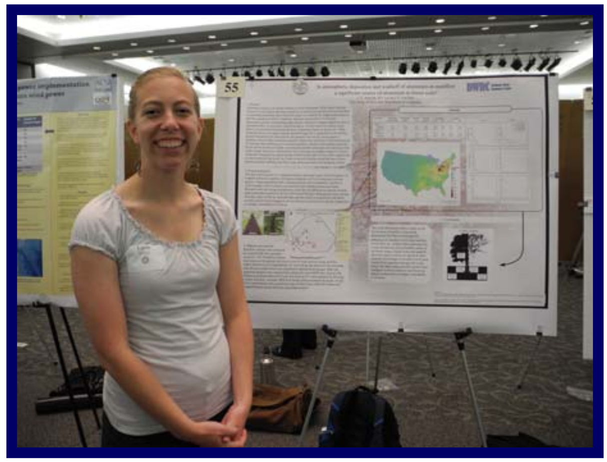
Basic Information

Title:	Is Atmospheric Deposition and Washoff of Aluminum in Stemflow a Significant Source
Project Number:	2011DE214B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	At large
Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Quality, Ecology, Hydrogeochemistry
Descriptors:	None
Principal Investigators:	Delphis Levia, Carrie Scheik

Publications

1. Scheick, C., and D. Levia. 2012. Is Atmospheric Deposition and Washoff of Aluminum in Stemflow a Significant Source of Aluminum to Forest Soils? Delaware Water Resources Center, University of Delaware, Newark, Delaware, 4 pages.
2. Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2 Introducing Our 2011-12 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 6.

Undergraduate Internship Project #7 of 8 for FY11



Intern ***Carrie Scheick's*** project, co-sponsored by the ***DWRC*** and the ***UD's*** Department of Plant and Soil Sciences titled "Is Atmospheric Deposition and Washoff of Aluminum in Stemflow a Significant Source of Aluminum to Forest Soils?" She was advised by Dr. Delphis Levia of the ***UD's*** Department of Geography.

Abstract

Aluminum toxicity is as serious concern in forest ecosystems. While much work has focused on soil solution aluminum chemistry in forests, less attention has been devoted to examining aluminum inputs from the canopy via washoff. No single study is known that has examined stemflow aluminum chemistry and stemflow Ca:Al ratios. Seasonality and the corresponding phenological conditions it triggers appears to have a detectable effect on aluminum washoff dynamics. In both leafed and leafless states, there is an intrastorm exponential decrease in aluminum inputs to forest soils. While aluminum fluxes were approximately threefold larger for *F. grandifolia* in the leafless period compared to the leafed period, the opposite was true for yellow poplar *L. tulipifera* where leafless aluminum stemflow fluxes were half those of the leafed period. We attribute these differences to increased stemflow volumes in the leafless period for beech and the much more highly concentrated stemflow aluminum concentrations from yellow poplar during the leafed period. The Ca:Al ratio in stemflow inputs is of such a magnitude (ranging from approximately 5-80 for beech and 5-18 for yellow poplar) that it could ameliorate the lower Ca:Al ratio in the soil solution around the base of trees, thereby possibly buffering trees from some stress associated with aluminum release.

White Clay Creek Wild and Scenic Shad Restoration Project

Basic Information

Title:	White Clay Creek Wild and Scenic Shad Restoration Project
Project Number:	2011DE215B
Start Date:	3/1/2011
End Date:	2/28/2012
Funding Source:	104B
Congressional District:	At large
Research Category:	Water Quality
Focus Category:	Ecology, Surface Water, Management and Planning
Descriptors:	None
Principal Investigators:	Gerald Kauffman, Chelsea Halley

Publications

1. Halley, C., and G. Kauffman. 2012. White Clay Creek Wild and Scenic Shad Restoration Project. Delaware Water Resources Center, University of Delaware, Newark, Delaware, 20 pages.
2. Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2 Introducing Our 2011-12 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 6.

Undergraduate Internship Project #8 of 8 for FY11

Intern ***Chelsea Halley's*** project, co-sponsored by the ***DWRC*** and the ***UD's College of Arts and Sciences*** was titled "White Clay Creek Wild and Scenic Shad Restoration Project." She was advised by Mr. Gerald Kauffman of the ***UD's*** Water Resources Agency.

Abstract

The long-term goal of the White Clay Creek watershed project is to restore shad and migratory fish passage and habitat, increase spawning areas, and benefit the resident fish in the 107-sq.-mi. watershed. The main objective in this stage of the project is to provide raw data that will aid in the decision whether or not to remove these dams. Methods used in this preliminary research include surveying the dams, conducting bioassessments of each site, obtaining water quality data, characterizing geomorphology if each site, and using HECRAS to chart results.

Surveying was conducted using a surveying pole, automatic level, and measuring tape. Cross sections at 100 foot intervals were used, 500 feet upstream and 500 feet downstream of each of the 6 sites. 10 foot intervals along each cross section were used to measure elevation. The bioassessment measures the diversity of the stream in terms of suitable habitat for living organisms. Using predetermined parameters, a score from 0-20 in 10 different categories was determined and put each site into a category of optimal, sub optimal, marginal, or poor. Water quality samples were taken downstream of each dam once a week to monitor pre-project conditions using pH, TDS, salinity, and conductivity probes. The Rosgen Stream Geomorphology Classification was used to characterize each site based on width-to-depth ratio, sinuosity, entrenchment ratio, water slope, and substrate composition. Lastly, all of the gathered information is entered into the Army Corps of Engineers HECRAS (Hydrologic Engineering Centers River Analysis System) program to model stream characteristics and stream bed topography. The model will then be used to assess the effects of removing or modifying each dam.

The results indicate that upstream of the dams was silt and sand, while downstream of the dams was cobble and gravel. According to the Rosgen Geomorphology Classification, every cross section was a Class A Stream between A3 to A6. According to the bioassessments, the biodiversity falls within the "marginal" and "suboptimal" categories. Our water quality data predict habitat compatibility with spawning sites for shad. More data are necessary and will be acquired in the future as the project progresses.

The field work that this project completed was the second year in a five-year project to allow the shad to swim up river to spawn. It is equally important to keep the integrity of the stream as similar as possible after the dams are removed. Before this summer's research, the creek was assessed and a feasibility report was written. During the spring of 2011, Dam 1 was surveyed, and all of the techniques to be used in the field were established. Our raw data will now be used to help receive funding for the next steps in this project.

Information Transfer Program Introduction

None.

DWRC Information Transfer

Basic Information

Title:	DWRC Information Transfer
Project Number:	2010DE197B
Start Date:	3/1/2011
End Date:	2/28/2012
Funding Source:	104B
Congressional District:	At Large
Research Category:	Not Applicable
Focus Category:	Water Quality, Water Supply, Education
Descriptors:	None
Principal Investigators:	Tom Thomas Sims, Maria Pautler

Publications

There are no publications.

Information Transfer Program

The following section describes all Delaware Water Resources Center information transfer activities during FY11, consolidating reporting into a single (extended) project **#2010DE197B**. Most activities from the DWRC's FY10 Information Transfer project (**#2010DE197B)** continued into this year.

The FY11 DWRC Information Transfer Activities include:

- Delaware Water Resources Center Electronic Publication WATER NEWS (2000 – 2006 = print; 2007 – present = electronic)
- Delaware Water Resources Center Electronic Newsletter WATER E-NEWS (2002 – present)
- Delaware Water Resources Center Website (3rd edition launched in 2009)
- Delaware Water Resources Center E-group / Courses Link (2002 – present)
- Delaware Water Resources Center Intern Project Poster Session / Advisory Panel Annual Meeting (2001 – present)
- Delaware Statewide Conference Co-sponsor and Participant (2001 – present)

Basic Information:

Delaware Water Resources Center Electronic Publication WATER NEWS

Title:	"WATER NEWS"
Issues during FY11:	Volume 11 Issue 2 (Winter 2010 – Spring 2011)
Description:	Online 8-page newsletter published biannually by the Delaware Water Resources Center
Lead Institute:	Delaware Water Resources Center
Principal Investigators:	Dr. J. Thomas Sims, Director; Maria Pautler, Editor

WATER NEWS is received electronically by over 275 recipients in water-related academic, government, public and private agency, agriculture and industry positions in Delaware and the surrounding area as well as 100 nationwide contacts for water resource issues. It may be accessed via the Delaware Water Resources Center website at: http://ag.udel.edu/dwrc/newsletters.html.

FY11 topics included:

- DWRC Annual Luncheon and Poster Session – April 22, 2011
- Introducing Our 2011-12 Interns
- Spotlight on Undergraduate Internships
- The UD WATER Project
- DWRC History, Goals, Advisory Panel, Contacts

Basic Information:
Delaware Water Resources Center Electronic Newsletter WATER E-NEWS

Title:	"WATER E-NEWS"
Issues during FY10:	Oct. 2011
Description:	Brief online "highlights" newsletter published periodically by the Delaware Water Resources Center
Lead Institute:	Delaware Water Resources Center
Principal Investigators:	J. Thomas Sims, Director; Maria Pautler, Editor

WATER E-NEWS is received electronically by over 275 recipients in water-related academic, government, public and private agency, agriculture and industry positions in Delaware and the surrounding area. The current issue and back issues dating to its July 2002 inception may be accessed via the DWRC website at: http://ag.udel.edu/dwrc/newsletters.html.

Featured in each issue of WATER E-NEWS are:

I. News items about the DWRC, including undergraduate internships and graduate fellowships
II. Jobs in Water Resources
III. Upcoming Water Conferences / Events
IV. Water Resources Information / Training

Basic Information: Delaware Water Resources Center Website

Title:	Website: http://ag.udel.edu/dwrc
Start Date:	Third edition; since February 2009
End Date:	Ongoing
Description:	Comprehensive site serving Delaware water resources community
Lead Institute:	Delaware Water Resources Center
Principal Investigators:	Dr. J. Thomas Sims, Director; Maria Pautler, Administrator

The website contains:

- **Delaware Water Resources Center (DWRC) and Director's News:** Latest updates on DWRC activities and information on the DWRC's mission, history, and role in the National Institute of Water Resources (NIWR).
- **Delaware Water Concerns:** Summary of the major areas of concern related to Delaware's ground and surface waters, with links to key organizations and agencies responsible for water quality and quantity.
- **Projects and Publications:** Descriptions of DWRC's undergraduate internship and graduate fellows programs, annual conference proceedings, and project publications dating back to 1993.
- **Advisory Panel:** Purpose, contact information and e-mail links for the DWRC's Advisory Panel.
- **Request for Proposals and Application Forms:** For undergraduate interns, graduate fellowships and other funding opportunities available through the DWRC.
- **Internships and Job Opportunities:** Information on undergraduate and graduate internships from a wide variety of local, regional, and national sources along with current job opportunities in water resource areas.
- **Water Courses and Faculty:** Link to search engine for current list of University of Delaware water resource courses. List of researchers at Delaware universities with an interest in water resources research; also, science and natural resource curricula links.
- **Water Resources Contacts:** Links to local, regional, and national water resource agencies and organizations categorized as government, academia, non-profit, and US Water Resource Centers.
- **Calendar:** Upcoming local, regional, and national water resources events sponsored by the DWRC and other agencies, such as conferences, seminars, meetings, and training opportunities.
- **Newsletters:** Access to DWRC newsletters dating back to 1993.
- **Annual and 5-year Reports:** DWRC annual and 5-year reports, dating to 1993.
- **KIDS' Zone:** Water resources activities and information for kids and teachers.

Basic Information: Delaware Water Resources Center E-group / Courses Link

Title:	Delaware Water Resources Center / Water Resources Agency E-group, originating from the online listing of Delaware water teachers and researchers found on the DWRC website: http://ag.udel.edu/dwrc/faculty_researchers.html
Start Date:	Since December 2001
End Date:	Ongoing
Description:	E-group and link to university water resources courses taught, serving Delaware water resources community
Lead Institute:	Delaware Water Resources Center
Principal Investigators:	J. Thomas Sims, Director; Maria Pautler, Administrator

The online listing of approximately 70 researchers at the University of Delaware, Delaware State University, and Wesley College found on the Delaware Water Resources Center website at http://ag.udel.edu/dwrc/faculty_researchers.html forms the foundation for a broader e-group list maintained by the DWRC reaching additional academic, public, private, and government water community contacts, who are notified via an e-mail newsletter of events and job postings of interest in water resources.

The website also links to a search engine and site for water-related courses currently offered by the researchers.

The total list of e-group members numbered approximately 275 as of February, 2012.

Basic Information:
Delaware Water Resources Center Intern Project Poster Session /
Annual Advisory Panel Meeting

Title:	University of Delaware 2012 Undergraduate Research Scholars Poster Session with DWRC Advisory Panel Meeting
Date:	April 20, 2012
Description:	Undergraduate interns presented their 2011-2012 DWRC-funded projects following the annual meeting of the DWRC Advisory Panel
Lead Institute:	University of Delaware Undergraduate Research Program Co-sponsors: Delaware Water Resources Center, Howard Hughes Medical Institute, Northeast Chemical Association, Charles Peter White Fellowship in Biological Sciences, Chemistry and Biochemistry Alumni Fellowship, EPSCoR, McNair Scholars Program, INBRE, College of Agriculture and Natural Resources, State of Delaware, Paradigm Fellowship, NUCLEUS
Principal Investigators:	Lynnette Overby, Director, UD Undergraduate Research Program (overbyl@udel.edu); J. Thomas Sims, Director, DWRC (jtsims@udel.edu)

On April 20, 2012, the undergraduate student interns who had been funded in 2011-2012 by the DWRC, accompanied by their advisors, presented the results of their research at an informal poster session sponsored by the University of Delaware Undergraduate Research Program. Over 90 UD Science and Engineering Scholars joined the DWRC interns to present to a crowd of over 500 visitors. The DWRC Advisory Panel also convened for lunch with the interns and their advisors and then held their annual meeting prior to the poster session. DWRC Director Tom Sims described the Center's plans for 2012-2013 with regard to research funding and public education outreach efforts.

Poster Presentations by 2011-2012 DWRC Undergraduate Interns – April 20, 2012

1) Aiken, Rebecca. Poster Presentation April 20, 2012. Education and Outreach for the Delaware Wetlands. 2012. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

2) Cannon, Amy. Poster Presentation April 20, 2012. An Analysis of the Impact of Marcellus Shale Development on Water Resources in Pennsylvania. 2012. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

3) Halley, Chelsea. Poster Presentation April 20, 2012. Prevalence of Pathogenic Bacteria in Delmarva Waters from a Virus Point of View. 2012. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

4) Harris, John Paul. Poster Presentation April 20, 2012. A Watershed Scale Forest Inventory of the Fair Hill Natural Resource Management Area Experimental Watershed in Relation to

Precipitation Partitioning. 2012. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

5) Scheick, Carrie. Poster Presentation April 20, 2012. The Impacts of Redefining “Navigable Waters” under the Clean Water Act. 2012. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

6) Spalt, Nicholas. Poster Presentation April 20, 2012. Characterization of Submarine Groundwater Discharge Sites in a Coastal Lagoon. 2012. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

7) Teoli, Kimberly. Poster Presentation April 20, 2012. Oyster Restoration Efforts at Delaware Inland Bays: Utilizing RIP-RAP as a Substrate for Oysters. 2012. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

Basic Information:
Delaware Statewide Conference Co-sponsor and Participant

Title:	Special Delaware Environmental Institute Symposium: “4th International Symposium on Global Issues in Nutrient Management Science, Technology and Policy”
Date:	August 21-24, 2011
Description:	Summary article is found in DWRC Winter 2010 – Spring 2011 WATER NEWS at http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , page 2
Lead Institute:	Delaware Environmental Institute Co-sponsors: Delaware Water Resources Center.
Principal Investigators:	Donald Sparks, Director, Delaware Environmental Institute (dlsparks@udel.edu); J. Thomas Sims, Director, DWRC (jtsims@udel.edu)

The DWRC, along with the Delaware Environmental Institute, hosted visiting scientists from China Agricultural University, the Agricultural University of Hebei, Wageningen University, the Agricultural Catchments Program at Teagasc, the University of Manitoba, and the United Nations Environment Program, among others, during the 4th International Symposium on Global Issues in Nutrient Management Science, Technology and Policy from August 21-24, 2011. More than 100 people were in attendance.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	8	0	0	0	8
Masters	0	0	0	0	0
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	10	0	0	0	10

Notable Awards and Achievements

Research Program: The Delaware Water Resources Center (DWRC) has funded ten research grant projects during March 2011 through February 2012 that address state water resources priorities identified by the DWRC's Advisory Panel. Two of these projects are graduate fellowships with research focuses on 1) quantifying carbon amount and quality for transport of contaminants in landscapes and 2) microbiome of the eastern oyster. The remaining projects were undergraduate internships researching 1) sediment transport through mill dams; 2) fungal predation of bacteria; 3) oyster gardening as a means of water filtration; 4) submarine groundwater discharge; 5) hydraulic properties of an aquifer; 6) hydrodynamic variability in a tidal creek; 7) atmospheric deposition and washoff of aluminum in stemflow; and 8) White Clay Creek Wild and Scenic shad restoration project.

Publications from Prior Years

1. 2009DE151B ("Biogeochemistry of Base Cations in a Broadleaved Deciduous Forest") - Other Publications - Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2, DWRC Annual Poster Session - April 23, 2010, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 3.
2. 2009DE153B ("Development of an Assay to Monitor the Activity of Fungal Enzymes in Soil") - Other Publications - Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2, DWRC Annual Poster Session - April 23, 2010, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 3.
3. 2009DE154B ("Flexible Compacts and Absolute Flows: Managing Interstate Basins for Competing Needs") - Other Publications - Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2, DWRC Annual Poster Session - April 23, 2010, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 3.
4. 2009DE155B ("Newly Constructed Wetland Management") - Other Publications - Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2, DWRC Annual Poster Session - April 23, 2010, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 2.
5. 2009DE157B ("Addition of Fine Particles Mitigates Flux Decline in Direct Contact Membrane Distillation") - Other Publications - Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2, DWRC Annual Poster Session - April 23, 2010, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 2.
6. 2009DE159B ("Investigation of Source and Dynamics of Bacterial Contamination in a Tidal Lake in Point Pleasant Beach, New Jersey") - Other Publications - Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2, DWRC Annual Poster Session - April 23, 2010, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 3.
7. 2009DE163B ("Physical Characterizations of Rapid Infiltration Basin Systems (RIBS) Used for Wastewater and Stormwater Disposal") - Other Publications - Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2, DWRC Annual Poster Session - April 23, 2010, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 3.
8. 2009DE164B ("Quality of Dissolved Organic Matter (DOM) in Runoff from Various Watershed Sources") - Other Publications - Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2, DWRC Annual Poster Session - April 23, 2010, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 2.
9. 2009DE167B ("Characterizing the Microbiome of the Eastern Oyster, Crassostrea virginica") - Other Publications - Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2, DWRC Annual Poster Session - April 23, 2010, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 3.
10. 2009DE168B ("Hydrology of Freshwater Marsh Nature Preserve, New Castle County, Delaware") - Other Publications - Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2, DWRC Annual Poster Session - April 23, 2010, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 3.
11. 2010DE177B ("The Use of Recycled Water for Irrigation of Turf and Landscape Plants") - Other Publications - Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2, DWRC Annual Poster Session - April 22, 2011, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 4.
12. 2010DE178B ("Education and Outreach for the Delaware Wetlands") - Other Publications - Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2, DWRC Annual Poster Session - April 22, 2011, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 3.

13. 2010DE181B ("Characterization of Submarine Groundwater Discharge Sites in a Coastal Lagoon") - Other Publications - Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2, DWRC Annual Poster Session - April 22, 2011, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 4.
14. 2010DE182B ("The History and Effectiveness of Wetland Mitigation") - Other Publications - Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2, DWRC Annual Poster Session - April 22, 2011, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 3.
15. 2010DE183B ("Assessment of Changes in Invertebrate Populations Resulting from Wetland Restoration") - Other Publications - Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2, DWRC Annual Poster Session - April 22, 2011, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 4.
16. 2010DE185B ("Quality of Dissolved Organic Matter in Runoff from Various Watershed Sources") - Other Publications - Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2, DWRC Annual Poster Session - April 22, 2011, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 4.
17. 2010DE186B ("The Impacts of Redefining Navigable Waters Under the Clean Water Act") - Other Publications - Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2, DWRC Annual Poster Session - April 22, 2011, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 4.
18. 2010DE187B ("An Analysis of the Impact of Marcellus Shale Development on Water Resources in Pennsylvania") - Other Publications - Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2, DWRC Annual Poster Session - April 22, 2011, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 3.
19. 2010DE188B ("The Prevalence of Pathogenic Bacteria in Delmarva Waters from a Virus Point of View") - Other Publications - Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2, DWRC Annual Poster Session - April 22, 2011, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 4.
20. 2010DE189B ("A Watershed Scale Forest Inventory of the Fair Hill Natural Resource Management Area ") - Other Publications - Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2, DWRC Annual Poster Session - April 22, 2011, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 4.
21. 2010DE190B ("Resurfacing Silver Brook Stream and Comparison to Connected Water Bodies") - Other Publications - Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2, DWRC Annual Poster Session - April 22, 2011, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 4.
22. 2010DE198B ("UD Watershed Team for Ecological Restoration") - Other Publications - Pautler, M., ed., 2011, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 2, DWRC Annual Poster Session - April 22, 2011, http://ag.udel.edu/dwrc/newsletters/Winter10Spring11/WATERNEWSco-Spring2011.pdf , p. 5.